Characteristics Chart of New Transistors

Condensed Summaries of Current Semiconductor Articles Appearing in Other Publications

Jan./Feb. 1958
75c

MICONDUCTOR PRODUCTS

Shockley 4-layer diode

Introduction to the Four-Layer Diode

The Spacistor • Transistor Physics

Variation of Transistor Parameters With Temperature

Transistor Heat Sinks and Their Evaluation

FREED

Offers for Immediate Delive

MINIATURE COMPONENTS

(MEET MIL-T-27A SPECIFICATIONS)

MINIATURE AUDIO TRANSFORMERS

Catalog No.	Input	Coupling	Power Level	Balanced DC Current	Unbalanced DC Current	Impedance Ohms	
			DBM	MA	MA	pri.	sec.
PMA-1	√		+8	0	0	50/200/500	60,000 center tapped
PMA-2	√		+8	0	0	4/8	
PMA-3	√		+8	0	0	50/200/500	
PMA-4		√	+8	0	0	15,000	
PMA-5		√	+8	2	2	15,000	
PMA-6	√		+8	0	0	15,000	50/200/500
PMA-7	√		+8	2	2	15,000	
PMA-8	√		+8	2	.25	30,000 ct	
PMA-9		√	+8	0	0	60,000	
PMA-10		√	+8	0	0	50/200	

All units ±2 DB 30 to 20,000~; PMA 5 and 7 ±2 DB 200 to 10,000~. Case size 15/16"D x 1½" high, flanges 1½" long.

TRANSISTOR TRANSFORMERS

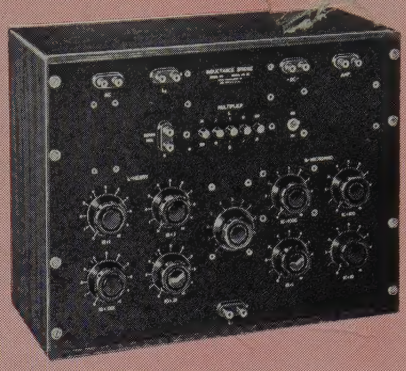
Catalog No.	200 to 15,000	300 to 15,000	Unbalanced DC Current	Max. Power Out	Impedance Ohms	
	DB	DB	MA	W.	pri.	sec.
TMA-1	±1		0	.25	500	500
TMA-2		±2	3	.25	50K	500
TMA-3		±2	3	.25	50K	6
TMA-4		±3	1	.25	100K	1.2K ct.
TMA-5	±2		3	.25	25K	1.2K ct.
TMA-6		±2	3	.25	50K	1.2K ct.
TMA-7	±1		4	.25	600/150	1.2K ct.
TMA-8	±2		3	.25	25K	600
TMA-9	±1		1	.25	4K ct.	600/150
TMA-10	±2		10	.25	2K	3.2
TMA-11	±1		1	.25	4K ct.	3.2
TMA-12		±2	4	.25	20K	50
TMA-13		±2	8	.25	1K	50
TMA-14		±2	0	.10	100K	1K
TMO-15		±2	1	.04	20K	50
TMO-16		±2	1	.04	20K	600
TMO-17		±2	3	.06	1K	50
TMO-18		±2	0	.10	100K	1K
TMA-19	±2		20	1.	1K	3.2

Case size 1"D x 1.5" high, flanges 1⅜". Specify TMO for open, TMC for encapsulated units.

MINIATURE HIGH Q TOROIDS

Cat. No.	Ind. MHY	Cat. No.	Ind. MHY	Cat. No.	Ind. MHY	Cat. No.	Ind. MHY
to 15 KC		10 to 50 KC		30 to 75 KC		50 to 200 KC	
F2050	1.	F2100	0.1	F2140	0.1	F2180	0.1
F2051	3.	F2101	0.2	F2141	0.2	F2181	0.2
F2052	5.	F2102	0.3	F2142	0.3	F2182	0.3
F2053	10.	F2103	0.4	F2143	0.4	F2183	0.4
F2054	15.	F2104	0.5	F2144	0.5	F2184	0.5
F2055	30.	F2105	1.0	F2145	1.0	F2185	0.6
F2056	50.	F2106	2.0	F2146	2.0	F2186	0.7
F2057	75.	F2107	3.0	F2147	3.0	F2187	0.8
F2058	100.	F2108	4.0	F2148	4.0	F2188	0.9
F2059	150.	F2109	5.0	F2149	5.0	F2189	1.
F2060	200.	F2110	7.5	F2150	7.5	F2190	2.
F2061	300.	F2111	10.	F2151	10.	F2191	3.
F2062	400.	F2112	15.	F2152	15.	F2192	4.
F2063	500.	F2113	20.	F2153	20.	F2193	5.
F2064	750.	F2114	30.	F2154	30.	Case size: ¾"x1 1/32" x25/32h.	
F2065	1,000.	F2115	50.	F2155	50.		
F2066	1,250.	F2116	75.	F2156	75.		
F2067	1,500.	F2117	100.	F2157	100.		
F2068	1,750.	Encapsulated 1"dx⅞"h. When ordering hermetically sealed units add H, encapsulated units MR to Cat. No.					
F2069	2,000.						

FOR PRECISION LABORATORY OR PRODUCTION TESTING



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1110-AB INCREMENTAL INDUCTANCE BRIDGE

AND ACCESSORIES

Accurate inductance measurement with or without superimposed D.C., for all types of iron core components.

- INDUCTANCE — 1 Millihenry to 1000 Henry
- FREQUENCY — 20 to 10,000 Cycles
- ACCURACY — 1% to 1000 Cycle, 2% to 10KC
- CONDUCTANCE — 1 Micromho to 1 MHO
- "Q" — 0.5 to 100
- SUPERIMPOSED D.C. — Up to 1 Ampere
- DIRECT READING — For use by unskilled operators.

ACCESSORIES AVAILABLE:
1140-A Null Detector 1210-A Null Detector - V.T.V.M.
1170 D.C. Supply and 1180 A.C. Supply.

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NULL DETECTOR AMPLIFIER TYPE 1140-A

USES

A sensitive null indicator for bridge measurements, providing visual null indications or aural when used in conjunction with headphones. The unit may also be used as a high gain amplifier for general laboratory work.

DESCRIPTION

Functionally the instrument consists of a high gain linear amplifier with a 30 db. input attenuator in addition to the variable gain control. A four-inch panel meter provides visual null indications, the response of the meter circuit is approximately logarithmic over a 40 db. voltage range. Resonant circuits tuned to 60, 400 and 1000 cycles limit the amplifier transmission characteristics to the three audio frequencies commonly used for bridge measurements or it may be used as a non-selective amplifier with filter "off."

SPECIFICATIONS

Input Impedance: 1 megohm in parallel with 25 mmf. GAIN: 98 db. with 1 megohm load (6 mmf. shunt capacity), down 1.5 db. at 25,000 cycles, down 5 db. at 50,000 cycles, down 2 db. at 20 cycles.
Null Detector Sensitivity: At 1 kc, 100 microvolts will give a 15% meter deflection.
Selective Amplifier: 26 db. second harmonic attenuation at 60, 400 and 1000 cycles.
Power Supply: 105-125 volts, 50-60 cycles, 35 watts consumption.
Dimensions: 13½" x 8½" x 10".

TELEMETERIN COMPONENT

BAND PASS FILTERS

Catalog No. Z_0=500Ω	Catalog No. Z_0=2,500Ω	3DB Bandwidth per cent of F_0 ± 9¾	3DB Bandwidth per cent of F_0 ± 19½	Center Frequency F_0 (KC)	Per cent Deviation of F_0 8½	15.	Per cent Linearity 0.5	1.
FBP-10	FBP-34	√		.4	√		√	
FBP-11	FBP-35	√		.56	√		√	
FBP-12	FBP-36	√		.73	√		√	
FBP-13	FBP-37	√		.96	√		√	
FBP-14	FBP-38	√		1.3	√		√	
FBP-15	FBP-39	√		1.7	√		√	
FBP-16	FBP-40	√		2.3	√		√	
FBP-17	FBP-41	√		3.0	√		√	
FBP-18	FBP-42	√		3.9	√		√	
FBP-19	FBP-43	√		5.4	√		√	
FBP-20	FBP-44	√		7.35	√		√	
FBP-21	FBP-45	√		10.5	√		√	
FBP-22	FBP-46	√		12.3	√		√	
FBP-23	FBP-47	√		14.5	√		√	
FBP-24	FBP-48	√		22.0	√		√	
FBP-25	FBP-49		√	22.0		√		√
FBP-26	FBP-50	√		30.0	√		√	
FBP-27	FBP-51		√	30.0		√		√
FBP-28	FBP-52	√		40.0	√		√	
FBP-29	FBP-53		√	40.0		√		√
FBP-30	FBP-54	√		52.5	√		√	
FBP-31	FBP-55		√	52.5		√		√
FBP-32	FBP-56	√		70.0	√		√	
FBP-33	FBP-57		√	70.0		√		√

DISCRIMINATOR LOW PASS FILTERS

Catalog No.	Center Frequency F_0 (cps)	Catalog No.	Center Frequency F_0 (cps)	Catalog No.	Center Frequency F_0 (cps)
OUTPUT					
LPO-10	6	LPO-19	81	LPO-28	790
LPO-11	8	LPO-20	110	LPO-29	900
LPO-12	11	LPO-21	160	LPO-30	1,050
LPO-13	14	LPO-22	185	LPO-31	1,200
LPO-14	20	LPO-23	220	LPO-32	1,600
LPO-15	25	LPO-24	330	LPO-33	2,100
LPO-16	35	LPO-25	450	LPO-34	7,200
LPO-17	45	LPO-26	600	LPO-35	10,000
LPO-18	60	LPO-27	660		
Characteristic impedance of all=330Ω					
INPUT					
LPI-10	400	LPI-17	3,000	LPI-23	14,500
LPI-11	560	LPI-18	3,900	LPI-24	22,000
LPI-12	730	LPI-19	5,400	LPI-25	30,000
LPI-13	960	LPI-20	7,350	LPI-26	40,000
LPI-14	1,300	LPI-21	10,500	LPI-27	52,500
LPI-15	1,700	LPI-22	12,300	LPI-28	70,000
LPI-16	2,300				
Characteristic impedance of LPI-10 thru 23=30,000Ω of LPI-24 thru 28=5,100Ω					

Send for NEW 48 page transformer catalog. Also ask for complete laboratory test instrument catalog.

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1792 WEIRFIELD ST., RIDGEWOOD, BROOKLYN 27, NEW YORK

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SEMICONDUCTORS

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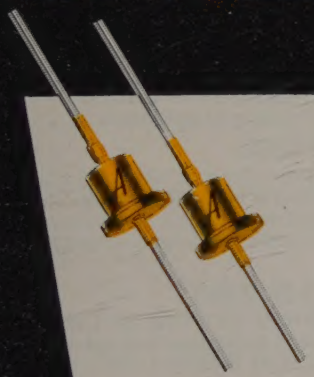
AUTOMATIC silicon rectifiers

designed to meet the NEW USAF specification MIL-E-1/1089



PIGTAIL TYPES*

1N538 (USAF)
1N540 (USAF)
1N547 (USAF)

* Do not confuse these USAF types with commercial types having the same numbers.

AVAILABLE FOR IMMEDIATE DELIVERY
IN LARGE SCALE PRODUCTION QUANTITIES

General Instrument's semiconductor manufacturing skill assures contractors fast delivery of these special new pigtail type silicon rectifiers now covered by this Air Force specification. AUTOMATIC's outstanding group of USAF type silicon rectifiers meets and often exceeds the rigorous MIL-E-1/1089 (USAF) specification – And expanded facilities permit us to deliver them in quantity at prices that reflect volume production.

AUTOMATIC MANUFACTURING DIVISION also offers the industry's most complete line of silicon rectifiers for an extensive range of applications including types for magnetic amplifiers, power supplies, D.C. blocking and germanium replacement, as well as types for general purpose use.

Would you like a set of our engineering data sheets? Please write us today!

Maximum Values for AUTOMATIC Military Type Silicon Rectifiers meeting MIL-E-1/1089 (USAF) Specification

Type No.	Peak Reverse Voltage (VDC)	DC Output Current @ 25° C. Ambient (MA)	DC Output Current @ 150° C. Ambient (MA)	Maximum Reverse Current* (MA)	Mounting	MIL-E-1 Technical Spec. Sheet No.
1N538 (USAF)	200	750	250	0.350	Pigtail	1089a
1N540 (USAF)	400	750	250	0.350	Pigtail	1089b
1N547 (USAF)	600	750	250	0.350	Pigtail	1089c

* Averaged over 1 cycle for inductive or resistive load with rectifier operating at full rated current at 150° C. ambients.

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DIVISION OF GENERAL INSTRUMENT CORPORATION
65 GOUVERNEUR ST., NEWARK 4, N. J.

AUTOMATIC silicon power rectifiers

STUD MOUNT TYPES

MILITARY TYPES — JAN SERIES 1N253, 1N254, 1N255 AND 1N256

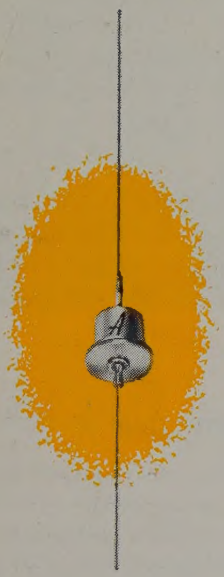
This series meets all the rigid electrical, mechanical and environmental requirements of MIL-E-1 specification. You are assured of highest quality and reliable performance.
Peak inverse voltages of 100 to 600 are available with DC ouput currents of 200 ma to 1 amp.

GENERAL PURPOSE TYPES — 1N550 THROUGH 1N555 SERIES

This series is suitable for all magnetic amplifier, power supply and DC blocking applications requiring 500 MA average rectified current over the range of 100 through 600 volts peak inverse.

HIGH VOLTAGE TYPES — 1N562 AND 1N563

These rectifiers cover the range of 800 to 1000 volts peak inverse with a DC output current of 400 MA. They are **single junction devices** offering the lowest possible forward voltage drop for high voltage service.



PIGTAIL TYPES

MILITARY TYPES — USAF SERIES 1N538, 1N540 AND 1N547

Peak inverse voltages of 200 to 600 are available with DC output currents of 250 ma at 150°C ambients. Meets all rigid requirements of MIL-E-1 specifications.

MAGNETIC AMPLIFIER TYPES — 1N440 THROUGH 1N445 SERIES

This series of rectifiers incorporate the most rigid electrical specifications currently being offered and has set the standard for the industry regarding quality for magnetic amplifier applications. Available with peak inverse voltages of 100 to 600 and DC output current of 300 MA.

POWER SUPPLY TYPES — 1N530 THROUGH 1N535 SERIES

Widely accepted for power supply applications, this series of rectifiers, which is available with peak inverse voltages of 100 to 600 and an average reotified current of 300 MA, has been used successfully in a multitude of military and commercial equipments.

GENERAL PURPOSE TYPES — IN1100 THROUGH IN1105 SERIES

This series of rectifiers, which is available with peak inverse voltages of 100 to 600 and an average rectified current of 250 MA at ambient temperatures of 150°C, is useful for all applications requiring a high quality rectifier. When used at lower ambient temperatures, rectifiers in this series can be operated at significantly higher DC output currents, namely, 750 MA at 25°C.

GERMANIUM REPLACEMENT TYPES — S-91 THROUGH S-93 SERIES

This series of rectifiers is designed to replace germanium types 1N91, 1N92 and 1N93. The advantages of silicon are offered at prices comparable to germanium, thus making this series admirably suited for use in commercial equipments where component cost is a factor.

HIGH POWER TYPES

5 AMPERE TYPES — AM0505 THROUGH AM3505 SERIES

This series of rectifiers covers the range of 50 to 350 volts with an average rectified current of 5 amperes at a case temperature of 135°C. Low leakage current makes high rectification efficiencies possible. These devices are very useful for the construction of various types of high power rectifier assemblies where a minimum of space is available and high operating temperatures encountered.

10 AMPERE TYPES — AM0510 THROUGH AM3510 SERIES

This series of rectifiers covers the range of 50 to 350 volts with an average rectified current of 10 amperes at a case temperature of 135°C. Low leakage current makes high rectification efficiencies possible. These devices are very useful for the construction of various types of high power rectifier assemblies where a minimum of space is available and high operating temperatures encountered.

20 AMPERE TYPES — AM0502 THROUGH AM3520 SERIES

This series of rectifiers covers the range of 50 to 350 volts with an average rectified current of 20 amperes at a case temperature of 135°C. Low leakage current makes high rectification efficiencies possible. These devices are very useful for the construction of various types of high power rectifier assemblies where a minimum of space is available and high operating temperatures encountered.

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MASS PRODUCERS OF ELECTRONIC COMPONENTS

Editorial . . .

ıjectives

the outset, our objectives are:

1) To provide current and authoritative information pertaining to the semiconductor industry and to the scientific personnel engaged in this industry.
2) To provide a medium for scientists to transmit their ideas, developments and investigations.
3) To provide a reportorial service wherein we will present helpful facts, figures and information from authoritative sources.

anks!

One of our first tasks in laying the groundwork for is magazine was to visit as many plants as we posbly could and interview the people engaged in mangement, research, applications, development and proıction. From these individuals we learned what they anted most in a magazine, and it is with this knowlge that we will shape our editorial policies to bring these people the kind of magazine they want; the nd of magazine that would provide them with the nd of information necessary to the best fulfillment their tasks.

We wish to thank everyone who has helped us ake the launching of this first issue of SEMICONUCTOR PRODUCTS possible. In particular, we ant to thank those people who took time out to adise and encourage us in our early efforts. To those eople we are deeply grateful.

evel

The articles and papers appearing in this magazine re intended to be on an engineering level, covering asic research, development, application and production of semiconductors and other solid-state devices, s well as their related products. It will be our policy o keep these articles on a level in which the necesary mathematics can be readily understood by the verage engineer. First and foremost in order of riority will be the kind of article that will help the ngineer in his research, design and production probems.

ransistor and Semiconductor Diode Charts

In this issue and in subsequent issues we are alernately providing characteristics charts of *newly announced* transistors and semiconductor diodes. The parameters and information listed in these charts are ntended to serve as a guide for the reader. A listing f all the characteristics and parameters would be physically impossible within the confines of our format. The parameters listed in this chart are the maximum we could conveniently include, and have been chosen after careful consultation with industry experts who kindly contributed their time and effort toward this end.

Condensed Summaries

Abstracts and summaries which appear in each issue are condensed versions of the original abstracts or summaries that accompanied the articles to which they refer. Space in this magazine does not permit lengthy abstracts nor can we cover all of the periodicals appearing throughout the world. Our service in this respect represents therefore an attempt to provide the reader with as many references as we can possibly make available.

Correspondence

Reader correspondence is heartily encouraged. This includes corrections to articles, criticisms, and other observations pertaining to any of the printed material appearing in this magazine. We will publish as many of these letters as space permits.

Transistorization

In a news release published in the New York Times on November 21, 1957 the story is told of a woman who, blind for 18 years, was able to see flashes of light during a Los Angeles hospital test. In this test wires were implanted in a certain section of her brain. These wires were then attached to a transistor amplifier which in turn was attached to a photocell serving as an electric eye. It would indeed be rash to venture overoptimistic conclusions from this remarkable feat. However, it is not beyond the realm of possibility that in the immediate future solid-state devices will be used with greater frequency and effect in conjunction with medical science and techniques.

In another news release dated October 31, 1957 in the New York World Telegram & Sun, we find reference made to a transistorized equipped electronic flashgun (strobe) which needs no power other than flashlight batteries. This unit (imported from Germany) yields a full year's supply of flashes (over 700) on a single battery change.

These are but a few examples of the ever-growing applications of transistors. As the versatility of solid-state devices becomes more and more apparent, their applications will become more universal. We have barely scratched the surface of development and application in this new and exciting industry.

S. L. Marshall

Designed for Computers

Made for Computers

Tested for Computers

Dependable in Computers

RAYTHEON RELIABLE COMPUTER TRANSISTORS

in the JETEC 30 package

Actual Size

Reliability must be designed and built into computer transistors. It cannot be obtained by selection.

Raytheon Computer Transistors were developed under Signal Corps contract and are manufactured especially for computer service, on a separate production line. They are backed by five years of experience in the mass production and quality control of Raytheon Fusion-Alloy Transistors.

Maximum stability is guaranteed by rigid test procedures including ***strict process control, 100°C baking*** of every transistor, ***100% steam cycling*** to assure positive hermetic sealing.

When you specify Raytheon Computer Transistors you are also assured of:

HIGH VOLTAGE RATINGS • HIGH CURRENT GAIN
FAST SWITCHING SPEED
LOW SATURATION RESISTANCE

Here are the electrical specifications for Raytheon PNP Computer Transistors

			2N425			2N426			2N427			2N428		
Parameter	Conditions (25°C)	Units	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
BVPT		volts	−30	−50	—	−25	−45	—	−20	−30	—	−15	−25	—
V_{BE_1}	$I_B = -1mA$, $V_{CE} = -0.25v$	volts	—	−0.35	−0.45	—	−0.35	−0.45	—	−0.35	−0.45	—	−0.35	−0.45
h_{FE_1}	$I_B = -1mA$, $V_{CE} = -0.25v$		20	30	40	30	40	60	40	55	80	60	80	—
h_{FE_2}	$I_B = -10mA$, $V_{CE} = -0.35v$		10	15	—	10	18	—	15	20	—	20	30	—
$R_{sat.}$	$I_B = -10mA$	ohms	—	2.2	3.2 for $I_C = -100mA$	—	2.2	3.2 for $I_C = -100mA$	—	1.4	2.1 for $I_C = -150mA$	—	1.1	1.6 for $I_C = -200mA$
$f_{\alpha b}$	$V_{CB} = -5v$, $I_E = 1mA$	Mc	2.5	4.0	—	3.0	6.0	—	5.0	11.0	—	10.0	17.0	—
C_{ob}	$V_{CB} = -5v$, $I_E = 1mA$	μμf	—	14	20	—	14	20	—	14	20	—	14	20
Switching Speeds														
$t_d + t_r$	$i_C = -50mA$, $R_L = 200$ ohms	μsec	—	0.53	1.0	—	0.53	1.0	—	0.43	0.85	—	0.43	0.85
t_s	Values of i_B "on" and i_B "off" are	μsec	—	0.3	0.6	—	0.3	0.6	—	0.3	0.6	—	0.3	0.6
t_f	5.0mA for 2N425 3.3mA for 2N426 2.5mA for 2N427 1.6mA for 2N428	μsec	—	0.45	0.65	—	0.35	0.55	—	0.35	0.55	—	0.30	0.50

For all types I_C (max.) = −400mAdc average
i_C (max.) = −1000 mA peak

Dissipation coefficient in free air = 0.4°C/mw
Dissipation coefficient with radiator = 0.28°C/mw
Dissipation coefficient with infinite sink = 0.18°C/mw

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Front Cover

Latest of the semiconductor devices to become a commercial product is the 4-layer diode illustrated on the front cover. Invented at Bell Telephone Laboratories by Dr. William Shockley this unit is described in an article beginning on page 9 in this issue.

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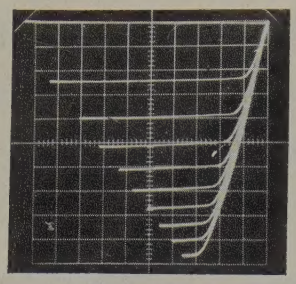
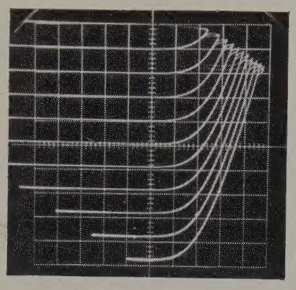


HIGH COLLECTOR CURRENT

PNP transistor, collector current vs collector voltage with constant-current base steps. Collector sweep is 0 to 5 v with a 0.25-ohm load, base current is 50 ma/step. Vertical deflection is 1000 ma/div, horizontal 0.5 v/div.



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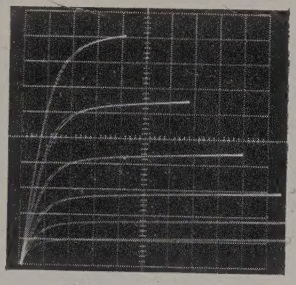

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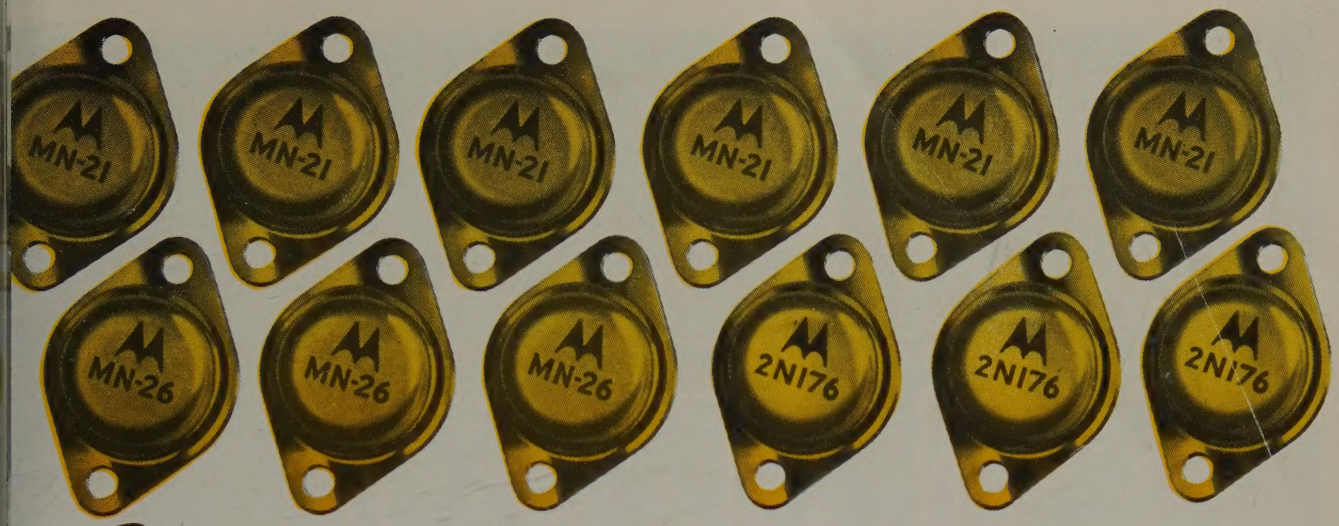

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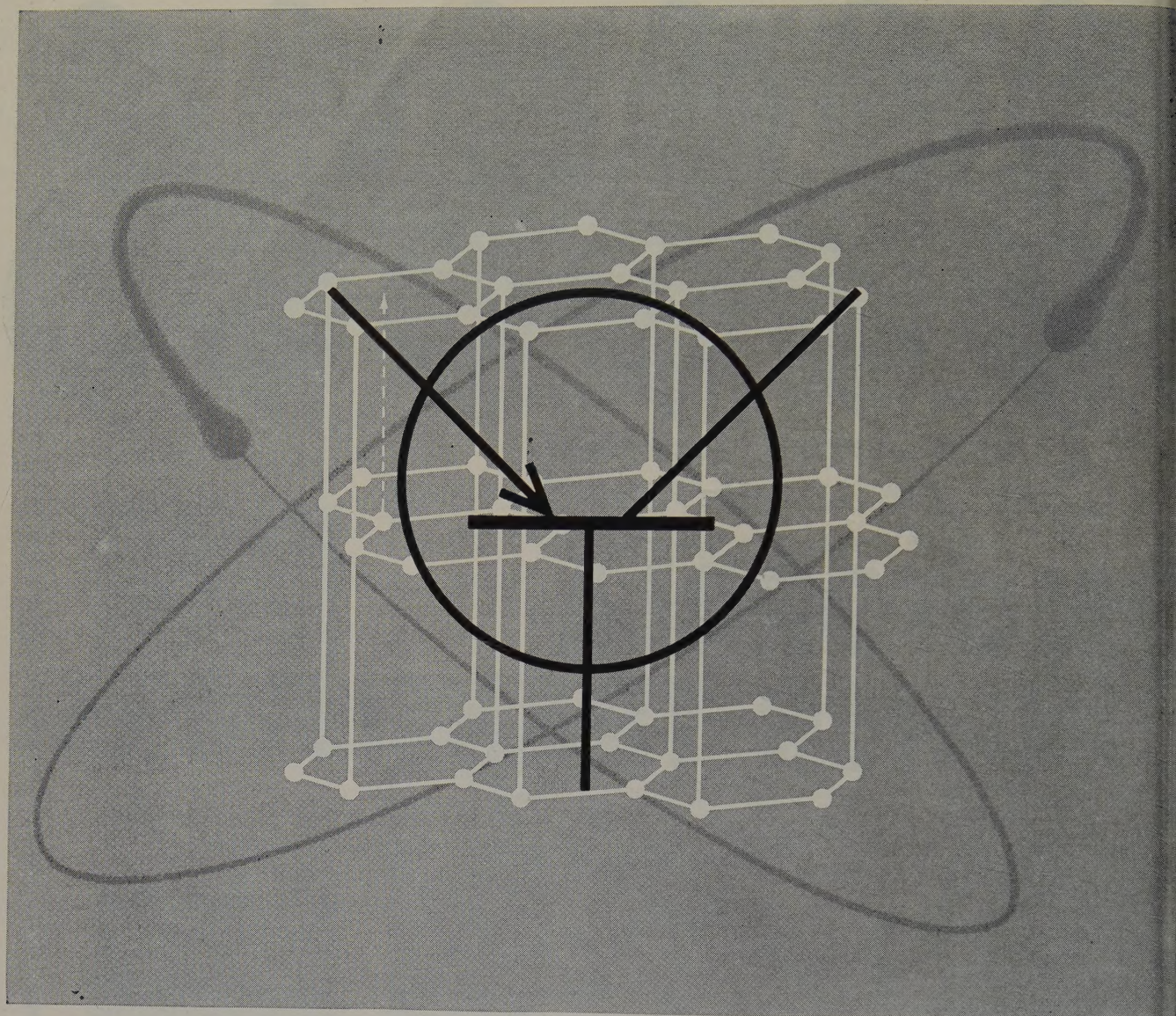

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Introduction to the Four-Layer Diode

DR. WILLIAM SHOCKLEY* DR. JAMES F. GIBBONS†

A description of the operation of a four layer diode is presented in terms of the device's voltage/current characteristic and internal semiconductor action. A qualitative description is given of the transition characteristic of the diode. Finally, the authors indicate possible applications of the device as a sine wave generator, saw tooth oscillator, bistable element for high power switching, and as a decade ring counter.

THE FOUR-LAYER diode, as its name implies, has four layers and is a two-terminal device. It is made of a single crystal of silicon and doped boron and phosphorous impurities diffused into it red heat. The four layers, alternately *p*-type and ype, result from the particular sequence of diffu- n, the depth from the surface being determined by time and temperature in accordance with known thematical laws of diffusion. The thickness of each er is about 0.0005 inches, and the total thickness the piece of silicon is about 2 thousandths of an h—about half the thickness of a sheet of paper. A ode contains a nickel-plated piece of this thin sheet ipped between two phosphor bronze pressure con- ts, the piece being approximately round and about 32 inch in diameter.

The techniques of fabrication of the four-layer ode are closely similar to those used in making ffused base transistors, and both devices were in- nted and first made at Bell Telephone Laboratories, e inventors being G. C. Dacey, C. Lee, and W. ockley, for the diffused-base transistor; and W. hockley for the four-layer diode.

In its functioning, the four-layer diode acts like two ter-connected diffused-base transistors, the two iddle layers being base and collector for the two ransistors, while the two outermost layers are the mitters. This combination of transistors constitutes closed feedback loop which is unstable if the gain round the loop is greater than unity. This instability eads to an increasing current which increases until uitable limiting factors in the external circuit bring t under control.

As a result of this type of instability, which will be liscussed more fully below, the four-layer diode has a current voltage characteristic with a negative resist- nce portion as shown in *Fig. 1*.

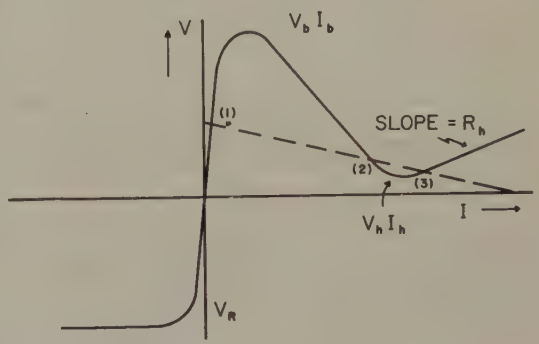

Fig. 1—Current voltage characteristic for a four-layer diode.

As is shown in *Fig. 1*, a typical load line will have three intersections with the *V-I* characteristic. The two outer intersections (1) and (3) are stable and the middle one (2) is unstable. If the supply voltage is raised from zero until it exceeds the breakdown voltage V_b and the load line is tangent to the characteristic at V_b, I_b, the device will make a transition from (1) to (3). If the voltage is then lowered until the load line is tangent near the "holding" point V_h, I_h, there will be a transition back to intersection (1).

Condition (1) is referred to as "open" or "off" and (3) as "closed" or "on."

For load lines of a few thousand ohms and voltage supplies of 20 volts or more, the difference in current between conditions (1) and (3) will be very large. For example, I_b may be as small as 0.05 *ma* so that the current in condition (1) may be less than 10 microamperes. On the other hand, the holding voltage and current may be only 1 volt at 5 milliamperes and the holding resistance only one ohm. Thus, in condition (3) the drop across the diode is very small compared to that in the load resistor. Thus, both in condition (1) and condition (2) the diode consumes very much less than is available to deliver to the load. In fact, circuits have been made in which four-layer diodes control 5 to 10 watts in a load while dissipating less than 0.1 watt themselves. One such circuit is discussed below.

* *Director, Shockley Semiconductor Laboratory of Beckman Instruments, Inc.*
† *Assistant Professor of Electrical Engineering Stanford University and Member of Staff of Shockley Semiconductor Laboratory.*

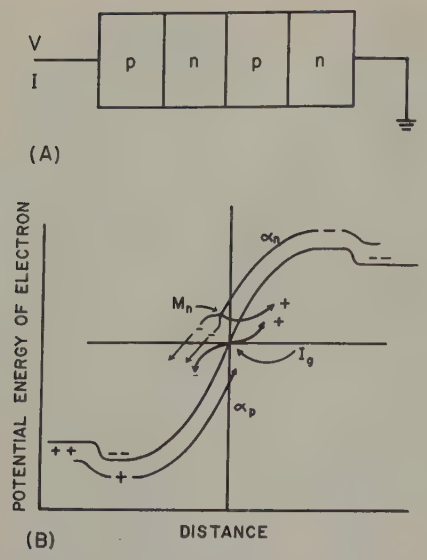

Fig. 2—The basic mechanisms in the four-layer diode. (a) The four-layer diode. (b) The corresponding potential energy diagram for electrons and holes.

Typical values for the five important parameters of *Fig. 1,* for devices produced at the Shockley Semiconductor Laboratory, are as follows:

V_b	50 *V*	(may be designed to be between 20-125 volts)
I_b	10 μa	(present specifications limit I_b to a maximum of 500 microamps)
V_h	1 *V*	(present specifications limit V_h to a maximum of 2 volts)
I_h	15 *ma*	(present specifications limit I_h to a maximum of 50 milliamps)
R_h	5 Ω	(present specifications limit R_h to a maximum of 20 ohms)

The Mechanism of the Transition

In order to understand how the *V-I* characteristic of *Fig. 1* comes about from an atomic point of view, it is necessary to understand two basically different effects which play cooperative roles in the phenomena. These are the increase in alpha of silicon transistors with increasing current and the phenomenon of avalanche multiplication in reverse biased junctions in silicon.

In *Fig. 2* these processes are indicated. The situation shown corresponds to a voltage somewhat less than V_b in *Fig. 1.*

Under these conditions, thermal generation of hole-electron pairs occurs in the reverse-biased center junction. If the voltage is high enough, this current may also be enhanced by secondary multiplication; this effect is not shown in connection with I_g in *Fig. 2.* As the voltage is increased, the width of the space charge layer increases and so does the multiplication so that the generated current increases. If the device were a simple *n-p* junction, this would give rise to the usual reverse characteristic of an avalanche or voltage-limiting diode.

Now we must consider the two outer junctions. The hole current from I_g arriving at the adjacent *p*-layer tends to give it a positive charge which would discharge the center junction capacity if the unit were open circuited. If the voltage is being held constant by a total current *I* through the unit, then this hole accumulation is prevented by forward bias across the *p-n* junction at the right. This *p-n* junction is in effect the emitter junction of an *n-p-n* transistor. The hole current from I_g arriving at the base layer produces forward bias and provokes an injected electron current through the *p*-layer.

Now it is a well-known property of silicon junction transistors that for them alpha increases with increasing forward bias. There are at least two theories for this effect; these lie beyond the scope of this article.[1, 2] It is also known from transistor theory that a current to the base produces a current $\alpha/(1-\alpha)$ times larger at the collector. Thus if $\alpha_n = 0.01$, the transmitted electron current represented by α_n in *Fig. 2* will be relatively unimportant. However, this electron current may be multiplied by an avalanche factor M_n before it reaches the *n*-layer to the left.

The mathematical theory of the current voltage characteristic can readily be formulated in terms of the picture just described. We shall not attempt to do so here, however, but shall try to describe the effects qualitatively.[3]

The breakdown voltage V_b of *Fig. 1* is such that avalanche multiplication makes up for the low values of alpha to the point that the gain approaches unity in the following sequence of processes: (1) holes arrive at *p*-type base layer provoking (2) electron current indicated by α_n which is (3) multiplied by M_n to (4) produce forward bias on the *n*-type base layer which (5) provokes hole current indicated by α_p which is (6) multiplied by avalanche to (7) produce more forward bias on the *p*-type layer. If the gain

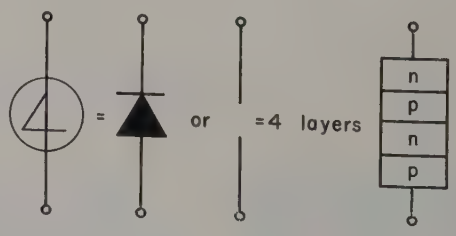

Fig. 3—The four-layer diode symbol. The diode acts either as an ordinary diode (when in the high current condition) or like a very high impedance (as if it weren't there). Hence the 4 can be thought of as a mutilated diode symbol.

[1] J. L. Moll, M. Tanenbaum, J. M. Goldey, and N. Holonyak, *Proc. I.R.E.,* Vol. 44, p. 1174, (1956).
[2] C.-T. Sah, R. N. Noyce, and W. Shockley, *Proc. I.R.E.,* Vol. 45, pp. 1228-1243, (Sept. 1957).
[3] For a discussion see reference 1 and also W. Shockley, *Electronic Industries* and *Tele-Tech,* Aug. 1957, page 58.

from (1) to (7) is greater than unity, the current will tend to build up spontaneously and to discharge the capacity at the center junction and reduce the avalanche gain so that a stable condition results. If the external impedance is so low that it prevents such a drop, destruction of the device may result.

The negative resistance portion of the characteristic comes about as follows: As the total current increases, the $\alpha/(1-\alpha)$ multiplication factors become larger; thus, the avalanche multiplication needed to sustain this current decreases. The avalanche multiplication depends on the voltage and decreases as the voltage decreases. Thus, increasing current results in decreasing voltage.

Finally, the current becomes so large that $\alpha_n + \alpha_p > 1$. Under these conditions electron flow between the two n-layers and hole flow between the p-layers become so efficient that like layers are effectively shorted together, and the device acts much like three p-n junctions in parallel, all biased forward. This gives the low resistance forward branch of *Fig. 1*. Much of the resistance in this branch arises from series resistance rather than junction resistances.

The build-up of current in the negative resistance part of the characteristic is very abrupt. In saw-tooth generators[3], for example, rise times of a few times 10^{-8} seconds are frequently obtained.

Typical Circuits

Some typical circuits in which units made at the Shockley Semiconductor Laboratory have operated successfully are described in connection with the following figures. The symbol used for the four-layer diode originates in the ideas suggested in *Fig. 3*.

a) V-I Plotter

This circuit is used for displaying the hysteresis pattern produced by a varying voltage upon the intersections (1) and (3) of *Fig. 1* (see *Fig. 4*).

Though the operation of the circuit is straightforward, it is necessary to take several precautions to insure that the device is not overheated while the *V-I* characteristic is being observed, since this can result in permanent damage to the unit. In particular, for

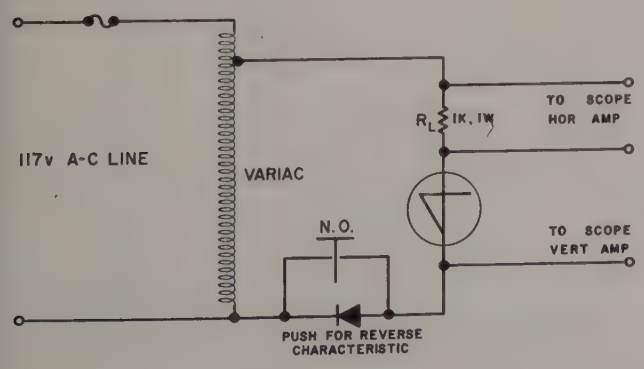

Fig. 4—V-I Plotter

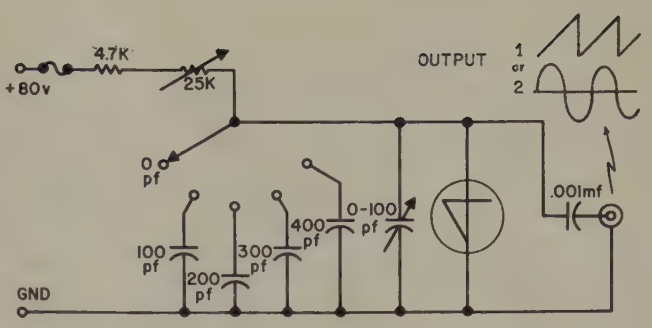

Fig. 5—Sine wave generator and sawtooth oscillator

60-cycle operation, the value of R_L should be selected to limit the forward current to about 300 *ma* peak. It is also a good practice to insert a conventional diode and a normally open pushbutton switch in the measuring loop, as shown. The reason for this is as follows: Since the reverse characteristic of the four-layer diode is similar to that of a typical "Zener" diode, considerable heating of the unit can result if it is allowed to pass a large current in the reverse breakdown condition. With the conventional diode in the circuit, the maximum voltage applied to the four-layer diode during the "reverse" portion of the *a-c* cycle will typically be much less than the reverse breakdown voltage (V_R in *Fig. 1*). The reverse characteristic can of course be viewed by shorting out the conventional diode with the switch, though this should not be done for an extended period of time.

b) Sine Wave Generator and Sawtooth Oscillator Applications

One of the simplest applications of the four-layer diode for the performance of circuit functions is as the active element in sine wave and sawtooth generators. A schematic diagram of the circuit is given in *Fig. 5*.

To understand the operation of the circuit in producing sawtooth oscillations, assume that the diode is in the open condition and the capacitor's voltage is increasing exponentially toward the supply voltage. When the voltage reaches V_b, the diode breaks down into the low resistance state, and the capacitor immediately discharges through the device. During this discharge time, the device is passing a current equal to the sum of the capacitor discharge current, and the current passed through the load resistor by the supply voltage—this sum being greater than I_h. When the total diode current falls below I_h, the diode returns to its high impedance state, and the charging cycle is again initiated. It is evident from this discussion that if the series resistor in *Fig. 5* is sufficiently small to allow a current greater than I_h to flow when the diode is in the conducting state, the diode will remain in the broken down condition once it gets there, and no sawtooth oscillations will result. Stated somewhat differently, the *d-c* load line provided by the voltage source and load resistor must intersect

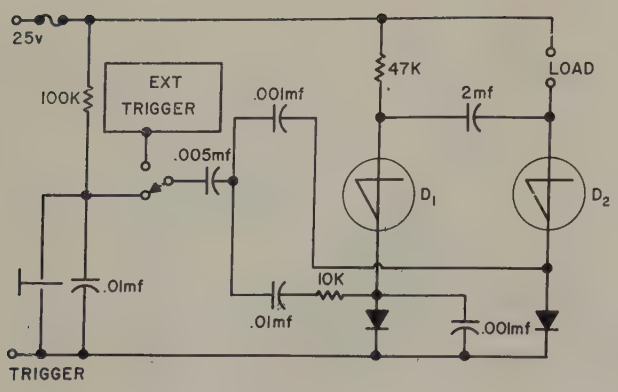

Fig. 6—Bistable circuit for high power switching

the *V-I* characteristic of the device only once, and that intersection must be on the negative resistance portion between V_b, I_b and V_h, I_h.

If the load line is adjusted so that this intersection occurs near V_b, I_b it is possible for the circuit to operate in the sine wave mode. For such oscillations it is necessary that (1) the negative resistance provided by the device exactly balance the positive resistance which the device sees in the external circuit, and (2) the negative capacitance which is also characteristic of the device in this range of operation be exactly balanced by the positive external circuit capacitance. The exact fulfillment of these requirements is possible for a range of values of supply voltage, so the circuit oscillation frequency is a voltage-dependent function.

Sine wave oscillation frequencies (and sawtooth repetition rates) as high as 10 *mc* and as low as 200 *kc* are readily obtained with this simple circuit. In addition, the sine wave frequency is voltage tunable over about a 10% band.

c) Bistable Circuit for High Power Switching

The extremely low impedance of the four-layer diode in the forward conducting state, coupled with the relative ease with which it may be driven to this state by a low-power input pulse, makes this device very suitable for high-power switching applications. A typical circuit which demonstrates these properties is given in *Fig. 6*. The operation of the circuit proceeds as follows: Suppose diode 2 is closed so that a current of 135 *ma*, say, is flowing through the load (perhaps a light bulb or relay coil). A negative input pulse under these conditions will see a forward biased conventional diode in the D_2 circuit, and will generate only a small pulse across it. In the D_1 circuit, however, the conventional diode presents a high impedance to the pulse and if the pulse amplitude V_p is such that $V_p + 25$ volts $\geq V_b$ for D_1, the pulse will be able to close D_1. This will in turn tend to divert the load current through D_1 via the 2 μf coupling capacitor, as well as apply a negative pulse to D_2 thus allowing D_2 to switch open. When the 2 μf capacitor has discharged, the load current will have dropped to zero and D_2 will remain in the open condition since the 25-volt supply voltage is not sufficient to switch D_2 on again. D_1 will also be open at this point of the operation since its 47 K load resistor will not allow a current as large as I_h to flow through D_1 in the steady state.

Application of a subsequent negative pulse of sufficient amplitude at the input will fire both D_1 and D_2, but D_1 will immediately return to the off condition due to the current-limiting action of the 47 K resistor. This, then, completes the operating cycle.

A noteworthy feature of this circuit is that *no* power is drawn from the 25-volt supply when the load is off. The circuit is capable of switching from 5 to 10 watts.

d) Decade Ring Counter

As a final example of the circuit applications of the four-layer diode, consider the decade ring counter shown in *Fig. 7*. When an input pulse is applied to this circuit, the voltage V_o will be brought to such a low value that the sustaining current I_h cannot be

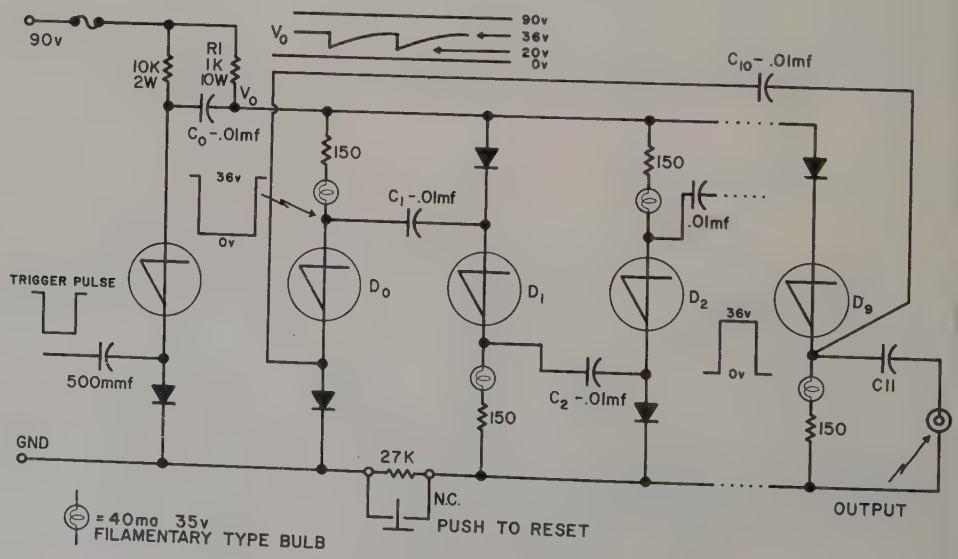

Fig. 7—Decade ring counter

rnished to any of the four-layer diodes through eir separate load resistor-lamp combinations.

Let us now assume that diode D_1 is conducting. hen the capacitor $C_2 = 0.1\ \mu f$ will be charged to the he voltage V_o ($= 36\ v$) through the conventional ode in the D_2 circuit. The application of an input ulse will cause C_o to discharge and will immediely turn off D_1, as previously described. The voltge V_o is now 20 volts, as shown in *Fig. 7*, and the apacitor C_2 has a stored voltage $V_{c2} = 36\ v$.

After C_o is discharged, the voltage V_o rises, producing a voltage across D_2 which is larger than that n any other diode in the ring by the voltage V_{c_2} hich is stored on capacitor C_2. This causes diode $_2$ to switch on before V_o reaches V_b. Since resistor $_1 = 1K\Omega$ has been selected so that the conduction urrent required by the D_2 circuit will hold the voltage V_o below V_b, no other diode circuit can be switched on at this time.

The circuit has thus changed its conduction state from circuit 1 to circuit 2 in response to an applied input pulse. By an entirely similar argument, it can be demonstrated that the circuit will change its conduction from circuit 2 to circuit 3 in response to the next pulse. The counting ring is closed by connecting a capacitor (C_{10}) from stage 9 to stage zero.

Various waveforms and voltage measurements which are typical of the circuit operation appear on the schematic. The output pulse is sufficiently large to drive another ring counter or counting relay as required. Circuits similar to this one have been operated at the Shockley Semiconductor Laboratory at rates as high as 100 *kc*, though this is certainly far from the limiting speed.

TRANSISTOR PHYSICS

BRUCE M. WILLIAMS*

The author discusses some of the basic principles of semiconductor physics. Initially, information on the element germanium is introduced, such as the atomic properties, conductivity, and electron and hole mobility. A discussion then follows on diode action and the "diode" equation is introduced. Finally, the author introduces the concept of transistor action developing the necessary associated equations.

OUR OBJECT in this brief summary on the topic of semiconductors is to discuss some of the principles of semiconductor physics and to describe some of the electronic devices made possible by the use of these materials. A rigorous treatment of the subject is not feasible, of course, but it is hoped that the following will serve as an introduction to this field and will stimulate the interest necessary to induce further investigation in the devices and applications to be described.

We propose to discuss three phases of semiconductor work:

1. First, we will consider materials: what a semiconductor is and how we can utilize its unique properties.
2. Second, we will explain a two-element semiconductor: the diode or rectifier, how it works and what it can do in an electric circuit.
3. The third topic will be the transistor: what it is, how it is built and some of its characteristics.

The term "semiconductor" is used to denote a solid material that does not have the ability to conduct electricity as well as a metallic conductor, but is a better conductor of electricity than an insulator. Since 1948, when the Bell Telephone Laboratories announced the development of the transistor, a great deal of work has been done in this field and many advances and refinements have been made in the understanding and use of such materials. There are many semiconductors. Some are elemental and others are made of compounds, but in this discussion, only the material germanium will be discussed. The same general discussion could be applied to silicon, and to some extent to compound semiconductors, but to economize time and simplify the presentation, the above limitation will be extended.

Most of us are familiar with the element germanium, as it is shown in the periodic table. It is in the

* *Texas Instruments Incorporated.*

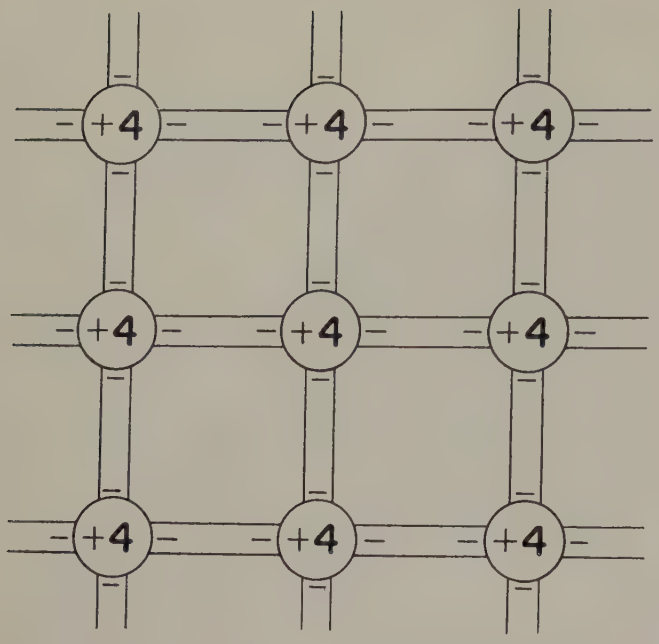

Fig. 1—Crystalline structure of germanium. Each circle represents the germanium nucleus and all electrons, except the valence electrons; and has an electronic charge of +4. Each — sign denotes a valence electron. The double lines between the nuclei represents the co-valent bonds that hold the atomic structure together.

IV column along with silicon, diamond, tin, and lead. The structure of the germanium atom is tetra-valent. It has in its outer electron orbit four electrons that are available to react or combine with electrons of other atoms. Under very carefully controlled conditions, we can cause molten germanium to solidify in a crystalline structure in which each atom is equidistant from four adjoining atoms. A planar representation of this is shown in *Fig. 1.* In this figure:

Each circle represents the germanium nucleus and all electrons, except the valence electrons, and has an electronic charge of +4.

Each minus sign denotes a valence electron. The double lines between the nuclei represent the covalent bonds that hold the atomic structure together.

The electron pairs or co-valent bonds can only be disrupted by the expenditure of considerable energy. In the case of germanium this energy is equal to 0.75 electron volts.

The structure shown in the sketch is not a true representation of the atomic situation because the thermal energy present at room temperature causes the crystal lattice to be in a state of continuous random agitation. As a result, one of the pair of electrons of a co-valent bond will occasionally acquire sufficient energy to break the bond and become free. The other electron remains behind and is available to acquire a new mate when the conditions are correct. Electrons that break away thusly are allowed to move freely, at random, through the crystal lattice. This action is similar to the motion of molecules in a gas.

If an electric field is impressed upon the crystal, the motion will be influenced by the field and the electrons will tend to drift toward the positive pole of the field. This resulting drift represents the flow of current carried by electrons.

Let us now return to the co-valent bond. When the electron broke loose, it left a void in the crystal structure. This void is called a hole. The hole will remain until the natural forces of the atomic structure, which cause electrons to arrange themselves in pairs, attract a free electron into the co-valent bond. This does not mean that the hole is destroyed, but rather that the location of the hole has shifted to the place from which the electron was taken. This means essentially that in addition to a random movement of electrons, we also have a random movement of holes.

If an electric field is present, the holes will drift toward the negative pole of the field. This drift represents a current flow which is transported by the absence of electrons. Since the flow is of opposite polarity and reverse direction, the net effect is an addition to the current carried by electrons.

We now have a condition prevailing in which the electrons and holes are being generated due to thermal agitation. They are recombining due to the natural forces in the crystal. Electron-hole pairs recombine at such a rate that the numbers of holes and electrons remain constant. This condition of equilibrium is strongly dependent on temperature; *i.e.*, the higher the temperature, the greater the number of pairs. This recombination rate is, in fact, proportional to the product of the concentrations of electrons and holes. The time of activity for any individual carrier then is limited and is defined as the "lifetime" of the carrier. It will range from less than 1 μsec to more than 1 millisecond depending upon the circumstances.

With the establishment of these concepts, we can visualize that the current flowing through a pure semiconductor is carried by two kinds of carriers—electrons and holes. The ability to conduct electricity, or the conductivity, σ, to an applied voltage can be represented by the equation:

$$\sigma = q(n\mu_n + p\mu_p)$$

Where

σ = the *drift* conductivity in mhos per cm,

q = the charge of the electron (or hole), 1.59×10^{-19} coulomb,

p,n = concentration of carriers per cubic *cm*, and

μ_n and μ_p = mobility of free electrons and holes, cm per sec/volt per cm.

It is important to note that the conductivity of a semiconductor is a measure of the concentration of current carriers present in the semiconducting materials.

Since a pure semiconductor is called an intrinsic semiconductor, the conductivity we have been discussing is the intrinsic conductivity and is designated by σ_i. It is, of course, assumed here that all of the carriers are generated when thermal energy breaks the covalent bonds. Electrons and holes are thus present in equal concentration and the equation can be simplified to

$$\sigma_i = q n_i (\mu_n + \mu_p)$$

and n_i is equal to $n = p$ and is called the intrinsic concentration.

We noted above that the concentration is very dependent upon temperature. In fact, the action of the electrons and holes in overcoming an energy barrier by means of thermal effects is very analogous to the emission of electrons from a hot cathode in a vacuum tube. The relation for intrinsic concentration is

$$n_i = AT^{3/2} e^{-qE/2KT}$$

Where

A is a constant for the material; 1.64×10^{15} for Ge,
T is the absolute temperature,
e is the natural logarithm base, 2.7182,
q is the charge on an electron, 1.59×10^{-19} coulomb,
E is the energy in volts required to break the covalent bond and is called the ionization energy, 0.75 V for Ge, and
k is Boltzmann's constant, 1.374×10^{-23}.

For germanium at room temperature (300°) $n_i = 2.5 \times 10^{13}$ electrons (or holes) per cubic centimeter.

The mobility of free electrons in germanium is 3900 *cm* per *sec*/volt per *cm* and, for free holes, 1900 *cm* per *sec*/volt per *cm*. A substitution of these values in our equation for conductivity shows that the intrinsic conductivity is 0.016 mho per *cm* or a resistivity ($^1/\sigma$) of 60 ohm-*cm*.

Note that since the flowing current is proportional to the conductivity, and since we have equal numbers of holes and electrons, two-thirds of the current that flows in an intrinsic semiconductor is carried by the free electrons. This is due to the higher mobility of the electrons.

Up to this point in our discussion, we have developed the concept of a pure or intrinsic semiconductor. We shall now discuss what happens when different types of impurities are added to the intrinsic semiconductor.

Suppose we add an atom that is penta-valent to the crystal lattice, or in other words, an atom that contains five electrons in its outer orbit. The relative amount of these penta-valent atoms will be very few, something like one-to-one million germanium atoms. These atoms could be phosphorous, antimony, arsenic, etc.

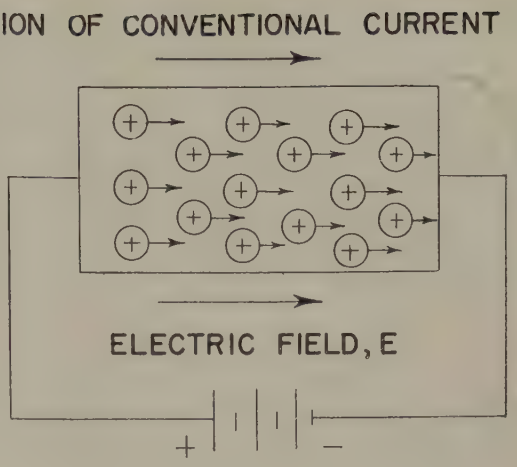

Fig. 2—Current flow in an "N" type semiconductor. The current that will flow can be given by

$$i_n = \sigma_n E = q\mu_n n_n E$$

Where i_n is the drift current/cm^2, σ_n is the conductivity of the "*n*-type" material in *mhos*/*cm*, and E is the applied electric field in volts/*cm*.

Since these impurity atoms are comparable in size to germanium atoms, they can take the place of the germanium atoms in the crystal, and, due to their small number, they should be completely surrounded by germanium atoms. Four of the five valence electrons will form co-valent bonds and become parts of the crystal lattice. The fifth electron, however, will be loosely bound to the parent atom. A force of only 0.01 electron volt is required to break this electron loose. It therefore will be very susceptible to energy and, when freed, will be capable of moving in the semiconductor in the same manner as the free electrons present in an intrinsic semiconductor.

These impurity atoms are called "donors," and the semiconductor is called "*n*-type." The electrons so supplied are called excess electrons. A similar situation exists with regard to holes, when an element from the III column of the periodic table, such as gallium or indium, is substituted for germanium in the crystal lattice. Such atoms are called "acceptors," and the semiconductor is called "*p*-type." Holes created in this way are called "excess" holes.

The conductivity of the impure semiconductors formed by adding donors or acceptors is altered appreciably by this addition. "*n*" and "*p*", the actual electron and hole concentrations, are determined by the number of electrons contributed by donors, the number of holes supplied by acceptors, the rate of generation of electron-hole pairs due to breaking covalent bonds, and by the rate of recombination of holes and electrons.

If we add donor electrons to the semiconductor, the concentration of free electrons is increased. This, of course, means that the holes that are present stand a much better chance of attracting an electron, and so the concentration of holes is decreased below the in-

trinsic value. Thus the conductivity of "*n*-type" semiconductors is due almost entirely to the free electrons. These free electrons are called the majority carriers, and the holes the minority carriers. The concentration of majority carriers approximates the concentration of the impurity atoms because the energy required to ionize (break the electron loose) is so small that practically every such atom has contributed to conduction. As a consequence, we can write the conductivity as:

$$\sigma_n \approx qN_D\mu_n$$

Where σ_n is the conductivity of the *n*-type semiconductor,
q is the charge on the electron,
N_D is the concentration of the donor atoms, and
μ_n is the mobility of the free electrons.

This is true because $n = N_D \gg p$.

The same situation holds for "*p*-type" semiconductors; *i.e.*, electrons reduced below the number in the intrinsic semiconductor, and with holes as the majority carriers and electrons as the minority carriers. The formula for "*p*-type" conductivity is:

$$\sigma_p \approx qN_A\mu_p$$

Where σ_p is the conductivity of the "*p*-type" semiconductor and
N_A is the concentration of the acceptor atoms.
μ_p is the mobility of the free holes.

When both acceptor and donor atoms are present simultaneously, the semiconductor is classified as either "*n*-type" or "*p*-type" according to whether electrons or holes carry the greater current, or whether the product $n\mu_n$ is greater or less than $p\mu_p$.

To give an idea of the magnitude involved, thermal agitation at room temperature will break one bond per 10^9 atoms. Therefore, one donor or acceptor per million germanium atoms will produce one thousand times as many carriers.

Let us now discuss what happens to these current carriers that we have defined, and then relate these effects to the operation of semiconductor devices.

In order to establish an electric current in semiconductors, it is necessary to connect the material to a source of emf by means of wires and metallic contacts on the semiconductor. We show diagramatically in *Fig. 2* the situation for "*n*-type" materials.
The current that will flow can be given by:

$$i_n = \sigma_n E = q\mu_n n_n E$$

Where i_n is the drift current/cm^2,
σ_n is the conductivity of the "*n*-type" material in mhos/*cm*, and
E is the applied electric field in volts/*cm*.

If the material is strongly *n*-type, the drift current of holes is negligible compared to that of electrons, so the entire current is i_n. We must also assume, of course, that the electron density remains constant at its equilibrium value n_n even though a current is flowing in the semiconductor.

Electrons flow out of the semiconductor at the left and into the semiconductor at the right. They flow at exactly the correct rate to account for the current flow expected because of the semiconductor conductivity. There is a voltage gradient present from one end of the semiconductor to the other which produces this electron drift and which represents the voltage drop.

Consider now the case of the "*p*-type" semiconductor in *Fig. 3*. The case is analogous to the "*n*-type" case and the current i_p is represented by:

$$i_p = \sigma_p E = q\mu_p n_p E$$

The drift current of the electrons is now negligible and the current can be assumed to be entirely due to holes.

We know now that i_p is carried by holes, and that in a metal the current is carried by electrons. It therefore is necessary to describe how this current can flow between the semiconductor and the metallic end contact. As holes reach the negative electrode, they combine with free electrons that they attract out of the metal of the negative electrode, and so disappear. Concurrently, replacement holes must be generated in the vicinity of the positive electrode. This occurs because as holes drift away from the positive electrode they no longer neutralize the negative charges of the immobile acceptor ions. An electric field is thus set up between the positive electrode and the nearby unneutralized negative acceptor ions which detaches the ionizing electrons from the acceptor atoms and draws them to the positive electrode.

When an acceptor atom loses an electron in this way, it acquires another electron from an adjacent co-valent bond in order to complete its own position in the valence structure. A new hole is then generated. The electron thus acquired is soon lost to the positive electrode; the process is repeated, and so on.

It is to be noted that the flow of current in the actual *p*-type material is the result of hole action, even though the current flow in the connecting wires and electrodes is still a movement of electrons.

Let us digress for a moment to discuss what happens when we bring two pieces of semiconductors together, one of "*p*" type and one of "*n*" type. This can be done physically in different ways, but let us assume that in the process of developing the crystal lattice we changed impurity types abruptly, causing the condition shown in *Fig. 4* to prevail.

We can show this condition in a two-dimension presentation as illustrated in *Fig. 5*. In this condition, the mobile carriers in each region remain at the same densities that they would have if the regions were separate, except in a very narrow region in the vicinity of the junction. The holes and electrons in the junction area combine, and the resulting uncovered

ions produce an electric field to drive the remaining holes and electrons away from the junction, which in turn uncovers more ions, etc. This field is called a "barrier field" and is on the order of 0.3 volt with the n region positive and the p region negative. A condition of equilibrium is finally reached between the n and p regions by mobile charges that are able occasionally to cross the junction.

With the polarity noted above, it is obvious that holes produced in the n region, by breaking co-valent bonds, flow freely across the junction. In fact, they are aided by the barrier field. The same situation applies for electrons in the p region. In the unbiased (no voltage applied) junction then, the current flow I_s of these intrinsic minority carriers is exactly counterbalanced by an equal and opposite flow of majority carriers which acquire from thermal sources the energy required for a carrier to travel across the junction against the barrier field. The width of the uncovered region adjusts itself so that the resulting value of the energy required makes the number of carriers crossing against the barrier field exactly equal to the number of intrinsic carriers that cross the junction with the aid of the field. Equilibrium is thus automatically maintained.

If the p material is biased positively with respect to the n material, the bias potential exerts a force on the holes, and on free electrons in the p and n material that opposes the restraining force of the barrier field. This force causes the carriers to crowd closer to the junction, and reduces the thickness of the region in which the immobile changes are uncovered, thereby reducing the energy needed to overcome the effect of the barrier field. It also permits more majority carriers to overcome the barrier and thus a large current flows.

When the bias is reversed, the applied potential causes the barrier field to widen. A greater amount of energy must now be expended before majority carriers can cross the junction. In fact, the reversed bias essentially stops the flow of majority carriers. However, the flow of intrinsic carriers is relatively unaffected by this change so a small reverse current I_s remains, termed the reverse saturation current. See *Fig. 6*.

These conditions are expressed by equations:

For an applied voltage V,

$$I = I_s(e^{\frac{qE}{kT}} - 1) \text{ amps per sq. cm.}$$

Where I_s is the reverse saturation current, *amps/sq cm*,
q is the electron charge 1.59 x 10^{-19} coulomb,
k is Boltzmann's constant 1.374 x 10^{-23}, and
T is absolute temperature, °K.

When the forward bias exceeds about 0.1 volt, the equation reduces to

$$I = I_s\, e^{39V}$$

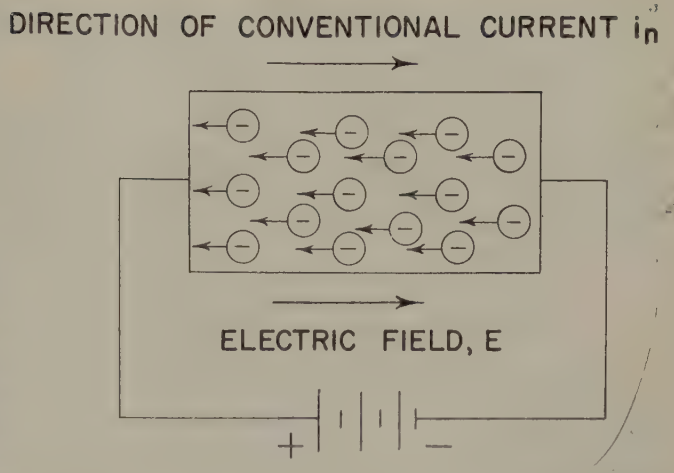

Fig. 3—Current flow in a "p" type semiconductor. The case is analogous to the "n-type" case and the current i_p is represented by

$$i_p = \sigma p\, E = q\mu_p\, n_p\, E$$

The drift current of the electrons is now negligible and the current can be assumed to be entirely due to holes.

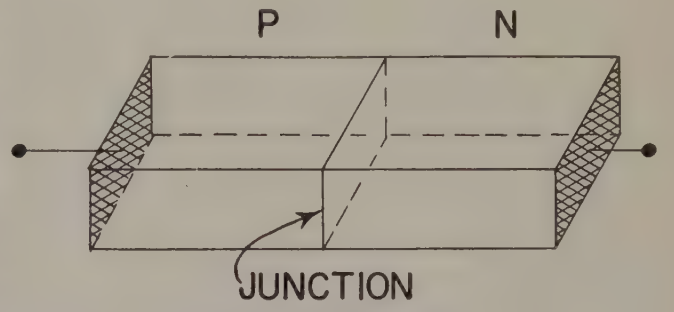

Fig. 4—A "p-n" junction.

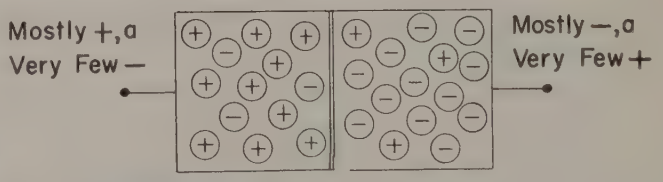

Fig. 5—Charge distribution in an unbiased "p-n" junction is shown above.

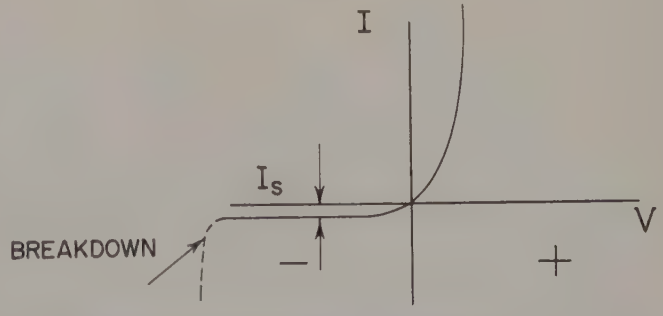

Fig. 6—Forward and reverse current flow in a "p-n" junction.

For a reverse bias greater than 0.1 volt the equation becomes:

$$I = I_s$$

Now we wish to extend our discussion further, to the case in which we have a *p-n* junction and we bias it (apply voltage to the ends). Let us start with a *p-n* junction in thermal equilibrium with carrier densities for typical conductivities of 100 $(ohm\text{-}cm)^{-1}$ and 1 $(ohm\text{-}cm)^{-1}$ for the *p* region and the *n* region respectively. (See *Fig. 7.*) When the *p* region is made positive with respect to the *n* region (forward bias), holes are injected into the *n* region, electrons are injected into the *p* region. The respective densities of holes and electrons so injected are greatest near the junction. The respective densities decrease toward the thermal equilibrium value as the distance away from the junction increases. These minority carriers recombine with the majority carriers to give the effect illustrated in *Fig. 8.* For about 0.1 volt, the value just inside the *p* or *n* region is about 50 times the thermal equilibrium value.

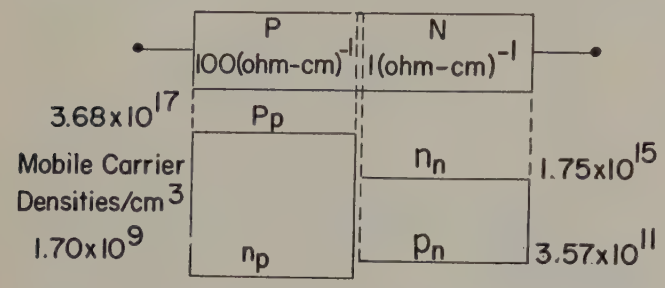

Fig. 7—Carrier densities in an unbiased "*p-n*" junction

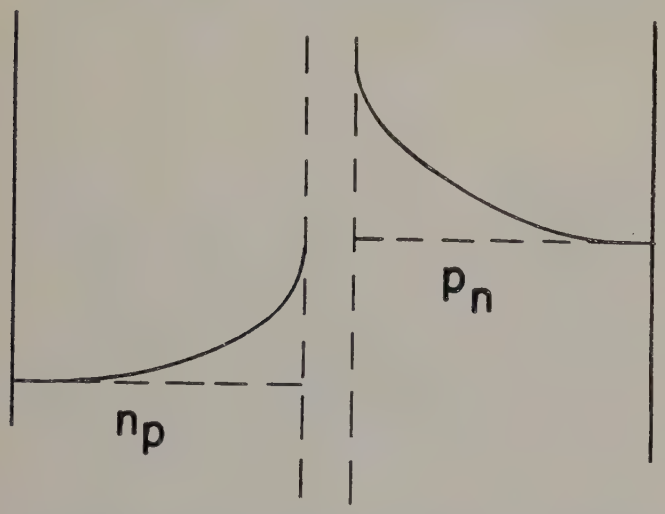

Fig. 8—Effect on minority carrier densities when forward bias is applied.

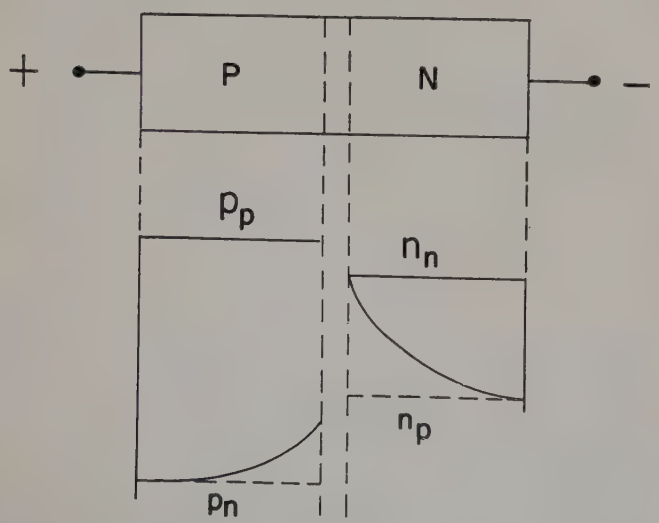

Fig. 9—Carrier densities in a forward biased "*p-n*" junction.

We know from intuition, if not from rigorous proof, that we must have charge equilibrium, and therefore the number of majority carriers must increase the same amount. Since, however, the density of majority carriers is so much greater than the density of the minority carriers, the majority carrier density remains essentially constant. See *Fig. 9.*

We note above a distinct difference in the method of causing the flow of current by these minority carriers; this mechanism is called diffusion. Were it not for the recombination that takes place, the two regions would attain new values of minority carrier density. However, as long as the applied voltage is maintained, holes continue to be injected across the junction into the *n* region, and the density of holes in the *n* region reaches the dynamic equilibrium distribution shown.

The diffusion of holes away from the junction into the *n* region constitutes a current because the carriers are charged. Such a current is called a diffusion current.

Diffusion flow occurs whenever the density of the carriers changes, or to put it another way, whenever there is a density gradient of carriers.

If the gradient is large, the current will be greater. We can deduce that the amount will be proportional to the gradient and the charge on the carrier. Therefore, we can write:

$$i_{dp} = qK \; grad \; p$$

and the constant of proportionality is called the diffusion constant for holes, D_p.

$$\therefore i_{dp} = qD_p\nabla_p$$

Where i_{dp} is the hole diffusion current per *sq cm*,
q is the charge on the hole (electron) in coulomb,
p is the hole density per cm^3, and
D_p is 44 cm^2/sec for germanium.

An analogous equation can be written for electrons, therefore

$$i_{dn} = qD_n\nabla_n$$

where i_{dn} is the electron diffusion current per *sq cm*,
q is the electron charge in coulombs,
n is the density of electrons per *cu cm*, and
D_n is the diffusion constant for electrons, 93 cm^2/sec for germanium.

We now have expressions for the complete current flow in a biased *p-n* junction. Two components are due to drift current and two components are due to diffusion current. Total currents of holes and electrons are:

$$i_p = q\mu_p pE - qD_p \nabla_p$$
$$i_n = q\mu_n nE + qD_n \nabla_n$$

The direction of both currents is the same in both cases; that of conventional current. Because of the opposite charge signs of holes and electrons, hole diffusion current flows in the direction of decreasing hole density, while electron diffusion current flows in the direction of increasing electron density.

We can show diagramatically the four current components in *Fig 10*. We may summarize by saying that for each type of carrier, drift current is proportional to the carrier density and to the potential gradient, while the diffusion current is proportional to the carrier density gradient.

One other point that should now be made is the definition of diffusion length, L. The distance L over which the concentration of the minority carriers is reduced by the factor $1/e = 0.37$, is termed the "diffusion length." It is related to the diffusion constant D and the average lifetime τ of the minority carriers by the equation

$$L = \sqrt{D\tau}$$

Let us re-examine in a little greater detail what we now have said.

1. When we have a *p-n* junction under an applied d-c potential, the concentration of majority carriers is relatively unaffected.
2. Concentrations of minority carriers are disturbed. The excess due to injection falls off exponentially with distance away from the junction.

We should note also at this time that the minority currents are subject to an unusual situation. That is, that the hole current depends on the physical properties of the n region and the electron current depends on the physical properties of the p region. Thus by altering the conductivities of these two regions, the ratio of the hole current to the electron current can also be altered. This is of great importance and is essentially what makes useful transistor action possible.

The stage is now set for our final developments. We have discussed at some length the characteristics of the junction under forward bias. Now we will discuss the junction under reverse bias (see *Fig. 11*).

The n and p region will be transposed since we are going to combine these two junctions, the n region being common. For the same reason, different conductivity values will be assigned; the n region is again 1 mho/*cm* but the p region is 0.1 mho/*cm*.

When a reverse bias is applied, the electrons and holes behave in a manner shown in the sketch. Minority holes in the n material that reach the junction by diffusion are transported into the p region by the barrier field. As a result of this steady removal of holes from the n side of the junction, the concentration of holes in the n material varies as shown in *Fig. 11*. This creates a concentration gradient that encour-

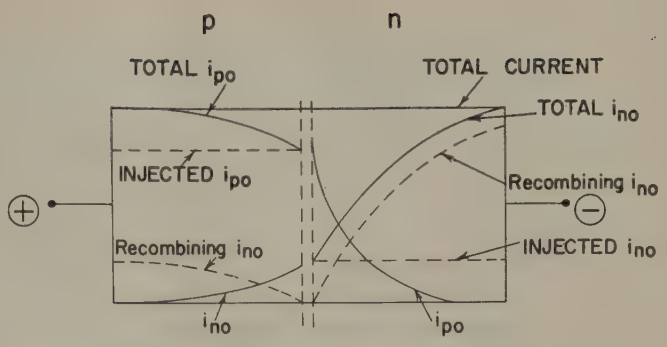

Fig. 10—Forward bias currents in a "*p-n*" junction.

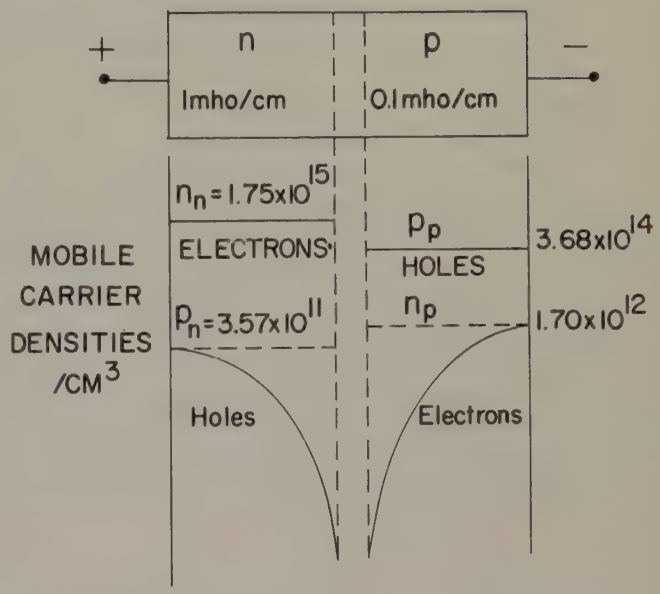

Fig. 11—Carrier densities in a reverse biased "*p-n*" junction.

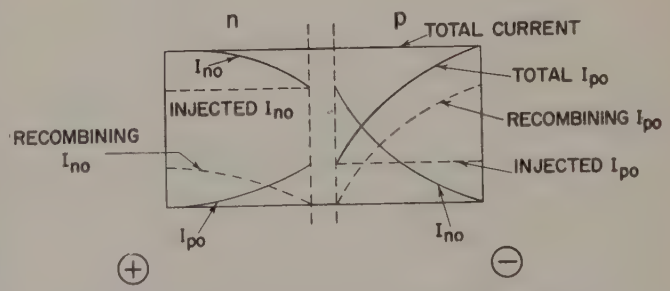

Fig. 12—Reverse bias currents in a "*p-n*" junction.

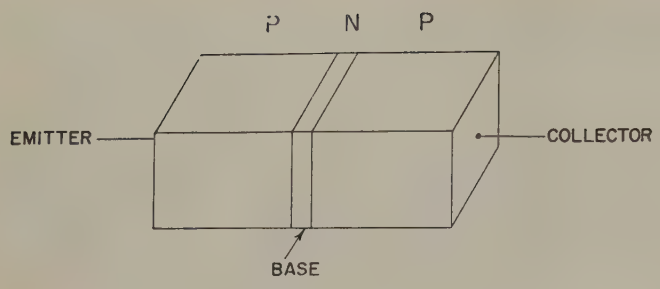

Fig. 13—A "*p-n-p*" transistor.

ages the few holes present as minority carriers to diffuse toward the junction. After entering the *p* material, the holes from the *n* region join with the holes in the *p* material and drift away from the junction. Minority electrons in the *p* material behave in a similar manner. The currents under reverse bias are shown in *Fig. 12*.

Let us now suppose that the length of the *n* region in our forward biased case is very much less than our diffusion length. This means that most of the injected holes are not able to recombine before they reach the end of the *n* region. If at this end of the *n* region we now place another *p* region and bias this *n-p* junction in the reverse direction, then the injected holes reaching this junction will be collected into the second *p* region. If the *n* region is small enough, practically all of the holes injected into the *n* region will be collected by the reverse biased *n-p* junction. Thus, we have a transistor. (See *Fig. 13*.)

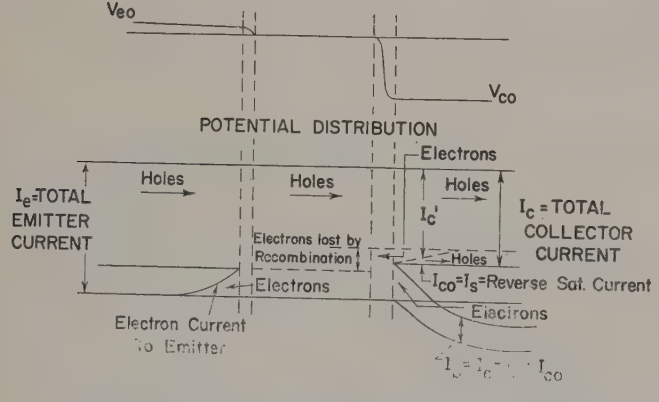

Fig. 15—Flow diagram of current and its components in a "*p-n-p*" transistor.

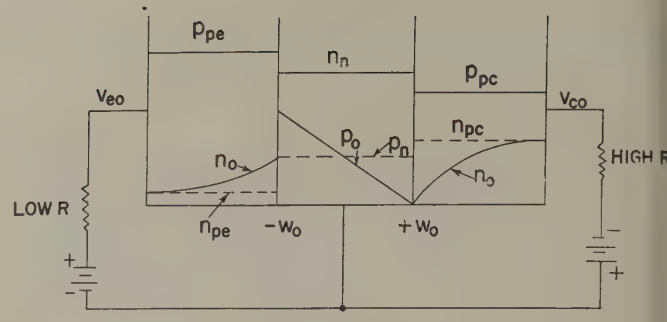

Fig. 14—Mobile carrier densities in a "*p-n-p*" transistor under normal bias.

The transfer of holes through the base from the emitter to collector constitutes transistor action. The hole current entering the collector is only slightly less than the emitter hole current. The small decrease is due to recombination in the base. Since the emitter is biased in the forward direction, it has a low resistance, and since the collector is biased in the reverse direction, it has a high resistance; hence, practically the same current emerges through a high resistance that entered through a low resistance. Thus power gain is produced, and a useful electronic device is obtained.

We can show the various carrier densities in a transistor, the potential distribution and a flow diagram of the current and its components in *Figs. 14* and *15*.

It has been the intent of this paper to explain some of the physical happenings in semiconductor devices. The details of device characterization and applications are so extensive that even a cursory glimpse would cover many more pages. The reader is referred to the excellent texts that are now available for these phases of the semiconductor art with the hope that the information presented in this paper will serve as a firm foundation upon which to base further and more detailed study.

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Diode Protection of Power Transistors from Temperature Variations and Voltage Surges

DR. H. C. LIN*

Transformer-coupled transistor amplifiers are often susceptible to temperature variations and voltage surges. The effect of temperature is to cause a variation in d-c conductance. The condition for voltage breakdown is aggravated by the presence of reverse bias at the base. These undesirable effects can be eliminated or minimized by the use of diodes, which have many advantages over other schemes.

TRANSISTOR stages, operating at high power levels, are often transformer-coupled to achieve high efficiency. *Fig. 1* shows a single-ended, transformer-coupled, transistor amplifier stage. *Fig. 2* shows a push-pull, transformer-coupled, transistor amplifier stage. In these amplifiers, the circuit *d-c* resistance is very low. This fact gives rise to problems which do not ordinarily exist in resistance-coupled amplifiers.

One major problem is the effect of temperature variation, and another is the problem of transient voltages. Due to the lack of *d-c* degeneration, the collector current of a transformer-coupled stage is quite sensitive to temperature variations. Such variations may introduce distortion, render the stage inoperative, or even permanently damage the transistor.

The effect of transient voltage is most pronounced in transformer-coupled amplifiers because of the absence of any limiting resistance. Consequently, a transistor in such a stage is more susceptible to destruction due to high-voltage surges. The transistor breakdown-voltage requirement of such a stage may be many times the supply voltage.

The foregoing undesirable effects may be reduced or eliminated by the use of diodes. The diode requirement for such purposes is less stringent than that for most other applications and, hence, permits the use of low-cost diodes. In addition, the temperature compensation diode also has many advantages over other means of compensation as will be discussed later.

Diodes For Temperature Compensation

The sensitivity of a transformer-coupled transistor stage to temperature is mainly due to the change in *d-c* transfer characteristics.[1] This can be seen in *Fig. 3*.

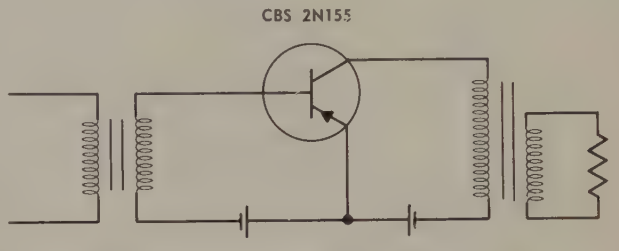


Fig. 1—Single-Ended transformer-coupled transistor amplifier circuit.

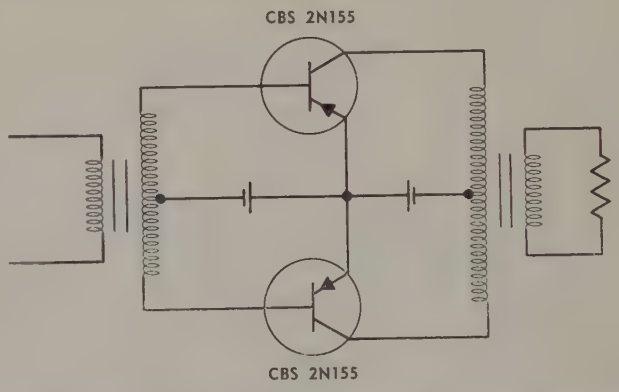


Fig. 2—Push-Pull transformer-coupled transistor amplifier circuit.

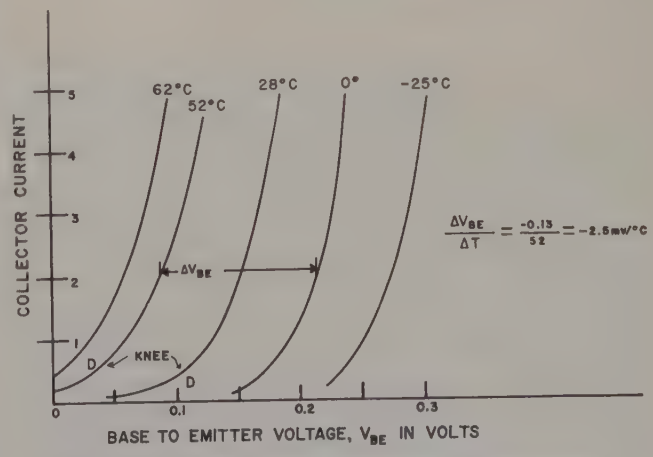


Fig. 3—Transfer characteristics of a transistor.

* *CBS-Hytron Semiconductor Operations, Lowell, Mass.*

[1] H. C. Lin and A. A. Barco, "Effect of Temperature in Circuits Using Junction Transistor," *Transistors I*, RCA Laboratories, 1956.

Note that as the temperature is increased, the transfer characteristics shift to the left. To maintain a constant collector current, the required base-to-emitter voltage should be reduced as the temperature is increased. The rate of shift is essentially a function of the semiconductor material and is approximately equal to 2 millivolts per degree centigrade.

On the other hand, if the base-to-emitter bias is held constant, then the collector current will undergo wide changes. At low temperatures, the transistor may be cut off. At high temperatures, the current may be so high as to exceed the dissipation limit of the transistor. For most applications, it is desirable to hold the *d-c* operating collector current nearly constant as temperature is varied.

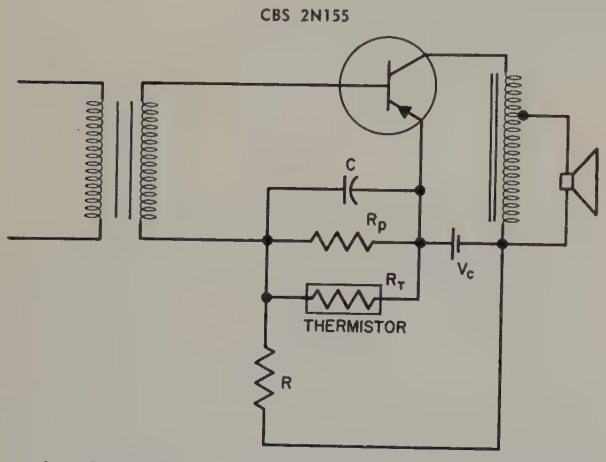


Fig. 4—Thermistor temperature-compensation circuit.

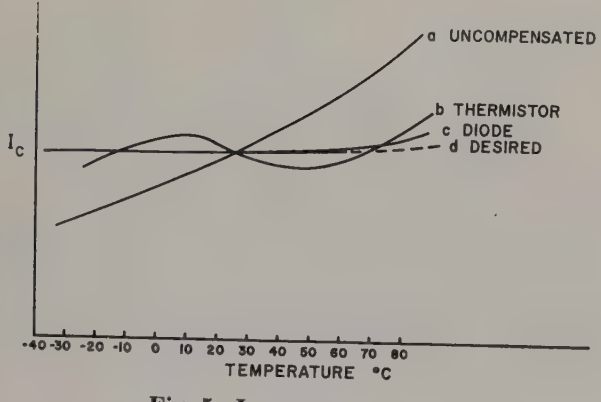


Fig. 5—I_C vs temperature.

To effect the desired change in bias for maintaining a constant collector current, some temperature-sensitive element is usually incorporated in the biasing network. One common scheme is to employ a negative-temperature coefficient thermistor in a circuit as shown in *Fig. 4*. Due to the different temperature characteristics of the thermistor, R_T, a padding resistor, R_p, must be used in conjunction with R to derive the proper variation of base-to-emitter bias with temperature. Nevertheless, it is only possible to "track" exactly at a few limited temperatures as shown in *Fig. 5*. In addition, since the thermistor is a resistance, it should be bypassed at signal frequencies to obtain maximum power gain.

A diode may be utilized to obtain temperature compensation in a manner similar to the thermistor. A class *A*, transformer-coupled, transistor amplifier can be temperature-compensated as shown in *Fig. 6*. The performance of this amplifier is shown in curve *c* in *Fig. 5*.

There are many advantages of using a diode instead of a thermistor. They are as follows:

1. Low a-c impedance

The forward characteristic of a junction diode is shown in *Fig. 7*. Note that there is a "barrier" voltage V_o (between 0.1 and 0.2 volt at 25°C for germanium diodes) below which the current is negligibly small. Conduction begins when the applied voltage exceeds V_o. The *a-c* impedance, r_D, of the conduction region as represented by the slope is usually very low for junction diodes. The *a-c* impedance is usually so low as to make the bypass capacitor unnecessary. On the other hand, in a biasing network using linear resistance, the *d-c* and *a-c* impedances are essentially the same and a bypass capacitor is ordinarily employed to avoid any reduction in power gain. For low frequency applications, the required capacitance may be quite high and expensive.

2. Low current drain

Because of the barrier voltage, the diode can be considered as having a built-in battery, V_o. Thus, it takes only a small voltage drop, Ir_D, to obtain the required base-to-emitter bias. For the same *a-c* impedance, the current drain for the diode biasing network is much smaller than any linear resistance biasing network.

3. Better temperature compensation

The characteristics of a junction diode and the base-to-emitter characteristics of a junction transistor are practically the same. For a diode, the shift in the forward characteristics with temperature is similar to that shown in *Fig. 3*. When the current through the diode is held constant at different temperatures, the voltage across the diode changes in the manner shown. If this change in voltage is applied between the base-

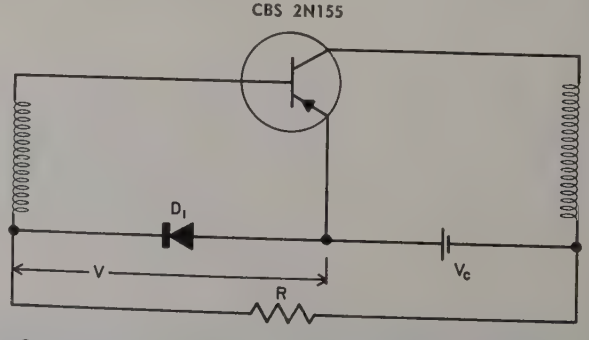


Fig. 6—Diode temperature compensation circuit. D_1 is a CBS LD-37.

mitter junction, the base current remains constant over a wide range of temperatures.

In comparison with a thermistor, the diode gives a better compensation as shown in *Fig. 5*. Note that the thermistor compensation "tracks" at only three temperatures with the desired current, whereas the diode compensation gives the desired current up to a very high temperature. The current of an uncompensated transistor is also shown in *Fig. 5*.

4. Lower sensitivity to supply voltage variations

As explained previously, a diode can be considered as having a fixed bias in series with a voltage equal to Ir_D. The current, I, is essentially equal to the supply voltage, V_C, divided by the dropping resistance, R. If V_C changes by ΔV_C the resultant change in I affects only the Ir_D portion of the base-to-emitter bias. If a diode is not used, the absence of V_o makes it necessary that all the required base-to-emitter bias must be derived from the IR_B drop across an external resistor, R_B. If I and V_C have the same values as in the diode circuit, then for the same variation of supply voltage, ΔV_C, a greater variation of base-to-emitter bias is experienced.

The requirement for the compensating diode can be derived by considering the diode and transistor characteristic equations. The forward diode current is given approximately as

$$I_D = I_{DS}\, e^{(V - I_D r_D)q/kT} \qquad (1)$$

where I_D is the forward diode current, V is the voltage between base and emitter or diode terminals as shown in *Fig. 6*, I_{DS} is the diode saturation current, q is the charge of a carrier, k is Boltzmann's constant, and T is the absolute temperature.

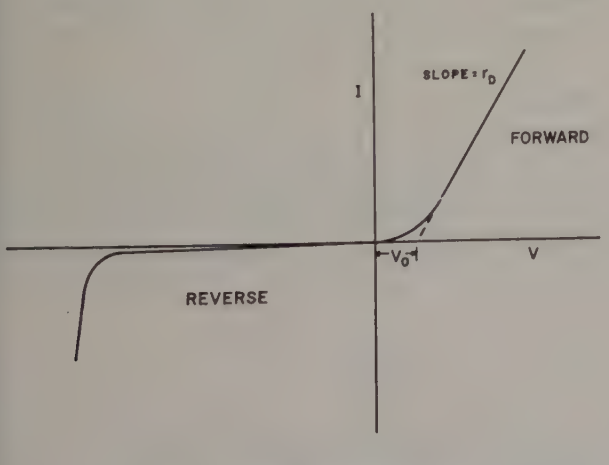


Fig. 7—Diode characteristic.

[2] L. J. Giacoletto, "Power Transistors for Audio Output Circuits," *Electronics*, Jan., 1954.
[3] M. Kidd, W. Hasenberg, and W. Webster, "Delayed Collector Conductance," *RCA Review*, March, 1955.

The collector current can be expressed in a similar manner:[2]

$$I_C = I_{CE}\, e^{[V - (I_C/\alpha_E - I_{BS})r_{BB'}]\, q/kT} \qquad (2)$$

where I_C is the collector current, I_{CE} is the current coefficient, $r_{BB'}$ is the base-lead resistance, α_E is the collector-to-base current amplification factor, and I_{BS} is the base saturation current.

In these expressions, the saturation current and the current coefficient are the most temperature-sensitive quantities, varying approximately exponentially with the difference in temperature. When I_D is held constant, the voltage across the intrinsic diode, which is equal to the applied voltage, V, minus the drop in the ohmic lead, $I_D r_D$, must change in such a direction as to cancel the change in I_{DS}. If the bases of the transistor and the diode are made of material of the same resistivity, the temperature dependence of I_{DS} and

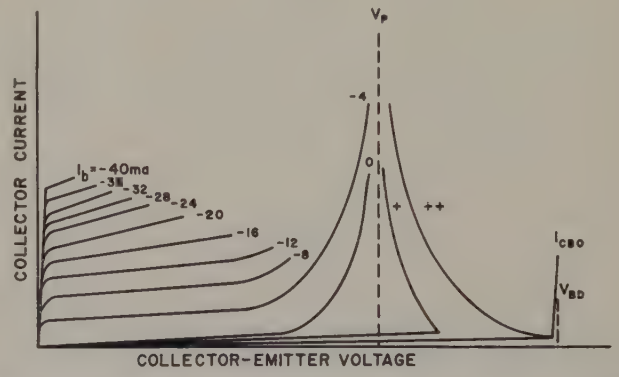


Fig. 8—Collector characteristics of a transistor (CBS 2N155).

I_{CE} should theoretically be identical; *i.e.*, the ratio I_{DS}/I_{CE} is an invariant. To hold I_B constant, the voltage between the intrinsic base and the emitter of the transistor, $V - (I_C/\alpha_E - I_{BS})r_{BB'}$, should equal $V - I_D r_D$, as can be seen from Eqs. (1) and (2). Over a wide range of temperature, I_{BS} is negligible. Then the ideal condition for temperature compensation is

$$I_C r_{BB'}/\alpha_E = I_D r_D \qquad (3)$$

Diode For Surge Protection

The typical collector characteristics of a *p-n-p* junction transistor is shown in *Fig. 8* with the base current as a running parameter. Note that when the base is reverse-biased, the curves exhibit negative resistance characteristics.[3]

In a transformer-coupled output stage, the maximum voltage swing is usually equal to two times the supply voltage for full sine-wave output. Thus, the transistor should have a breakdown voltage, V_p, at least twice as large as the supply voltage. Ordinarily, a transformer has some leakage inductance. In addition, the load may not be purely resistive so that

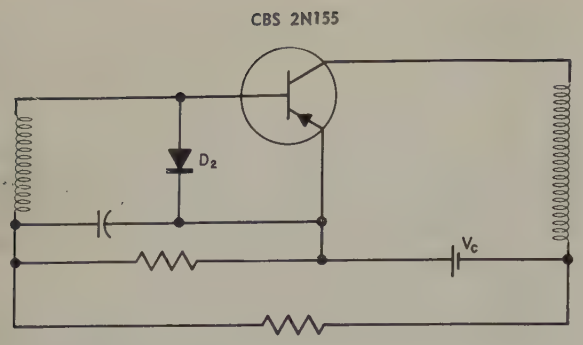


Fig. 9—Junction diode protection circuit.

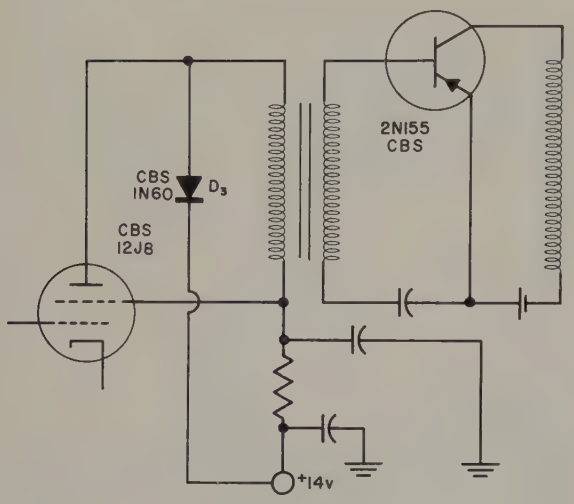


Fig. 10—Point-Contact diode protection circuit. Used in this circuit are a CBS 2N155, a CBS 1N60 (D_3) and a CBS 12J8.

there is some reflected inductance. When the current is suddenly cut off in an inductive load, such as due to excessive noise or the removal of the driver, the surge voltage may be much higher than twice the supply voltage. If the surge exceeds V_p and reaches the negative resistance region of the collector characteristic, oscillation may follow. This oscillation may create high dissipation in the transistor and often results in a short circuit between the collector and the emitter. A transistor may be protected either by limiting the maximum surge to a low voltage, or by preventing the base of the transistor from reverse-biasing so that the condition for negative-resistance collector characteristics does not exist. The methods of reducing voltage surge, such as Zener diode, neon tube, varistor, capacitor or *R-C* network, are well known and will not be discussed here.

The following description concerns only the use of diodes for preventing the base from reverse-biasing. *Fig. 9* shows one possible scheme. A junction diode, D_2, is connected across the base and the emitter of a *p-n-p* transistor. The anode of the D_2 is connected to the base and the cathode to the emitter. Under normal operating conditions, D_2 is reverse-biased and, therefore, does not affect the operation of the transistor. However, if there is any surge appearing at the input tending to reverse-bias the transistor, the diode becomes conductive and, thus, prevents the transistor from being reverse-biased.

Another method is to use a diode, D_3, (which may be a point-contact type) across the primary of the input transformer as shown in *Fig. 10*. Diode D_3 should normally be reverse-biased so as not to interfere with the desired signal. The *d-c* circuit and transformer resistance may sometimes give an adequate voltage drop to provide the reverse bias. When the input is suddenly cut off, the voltage surge created drives the diode into conduction, thereby limiting the surge. If the transformer is phased in such a direction that the limited surge in the primary prevents the base from reverse-biasing, then the transistor will be protected from destruction.

The advantage of the two foregoing methods is that the limiting action is achieved by the forward conduction of the diodes. Since the threshold voltage at which conduction begins is approximately the same for all diodes of the same type, and since the reverse characteristic is unimportant, the diode requirement for this application is not at all critical. Almost any junction diode can function in the circuit shown in *Fig. 9*. It is likewise true that any diode (including the point-contact type) can work satisfactorily in the circuit shown in *Fig. 10*. Compared with Zener diodes, the present schemes are much less expensive.

Conclusions

Temperature compensation and high-voltage reduction are important considerations in transformer-coupled power transistor stages. These problems can conveniently be solved by means of inexpensive diodes.

Variation of Transistor Parameters with Temperature

C. R. ESHELMAN*

This paper presents a theoretical discussion of the quantitative variation with temperature of transistor hybrid-π equivalent-circuit parameters, using the equations developed by Giacoletto.[1] Experimental variation of these parameters is also given. The transistor used is a typical small-signal audio *p-n-p* alloy-junction transistor, RCA-2N77, which is of similar construction to that used by Giacoletto. Excellent quantitative agreement between theoretical and experimental results is shown.

The four admittance parameters were measured on an impedance bridge at an emitter current of 1 milliampere, a collector-to-emitter voltage of −6 volts, and a frequency of 1 kilocycle. The resistance and susceptance parameters were measured using the admittance bridges developed by Giacoletto.[2] Results of these measurements were converted into the hybrid-π equivalent-circuit parameters using the equations referred to above.

INTRODUCTION

A P-N-P GERMANIUM alloy-junction transistor in a common-emitter circuit may be represented by the "hybrid-π" equivalent circuit shown in *Fig. 1*. This equivalent circuit and the equations for the intrinsic (e') parameters were derived by Giacoletto.[1] Giacoletto, in the referenced paper, also presented quantitative data on the variation of the hybrid-π circuit parameters with current, voltage, and frequency.

The present paper describes the variation of the "hybrid-π" equivalent-circuit parameters with temperature. It gives the theoretical variations in these parameters (determined from Giacoletto's equations[1]) and compares them quantitatively and qualitatively with those obtained experimentally.

The transistor used as the subject of this study was the RCA-2N77, a small-signal type designed for *a-f* applications similar to the one used by Giacoletto.[1] The conductance parameters $e'g_{b'e}$, $e'g_{b'c}$, and $e'g_{ce}$ were derived from the two-generator equivalent-circuit parameters g_{bbe}, g_{bce}, g_{cbe}, and g_{cce}, which were measured on a General Radio Type 561-D Vacuum-Tube Bridge,[2] using an emitter current I_E of 1 milliampere, a collector-to-emitter voltage V_{CE} of −6 volts, and a frequency of 1000 *cps*. The resistance parameter $r_{bb'}$, and the susceptance parameters $e'C_{b'e}$ and $e'C_{b'c}$ were determined from measurements made on admittance bridges developed by Giacoletto.[2]

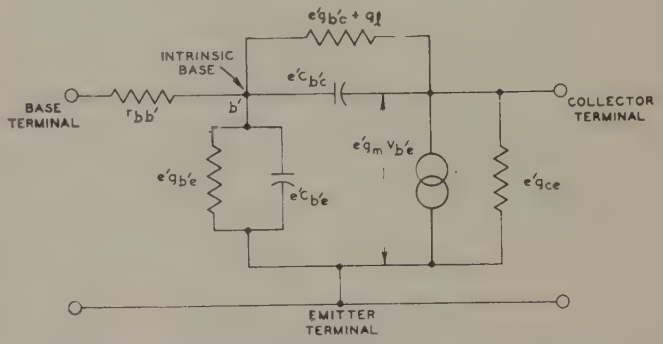


Fig. 1.—"Hybrid-π" equivalent circuit of *p-n-p* alloy-junction transistor (common-emitter connection).

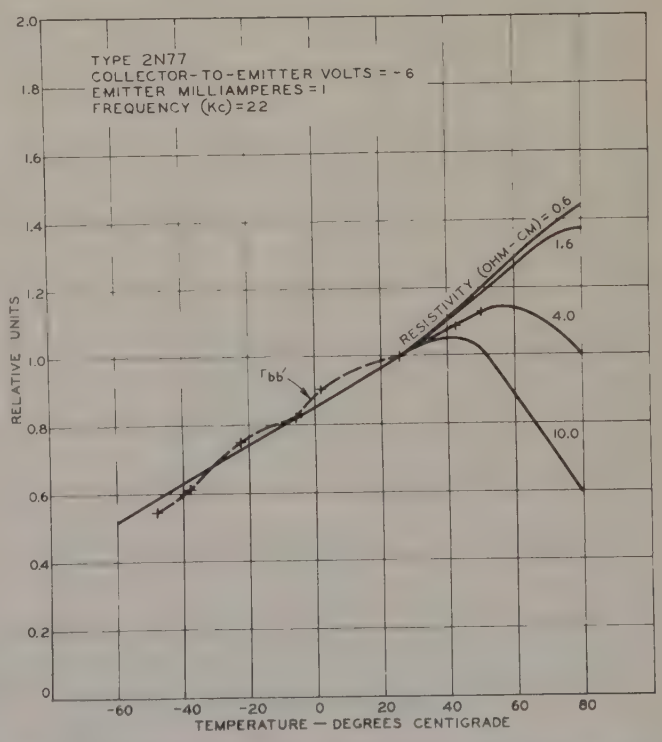


Fig. 2—Variation with temperature (normalized to 25°C) of resistivity of *n*-type germanium (solid curves), and measured resistance parameter $r_{bb'}$ for RCA-2N77 transistor (crosses).

*Semiconductor Division, Radio Corporation of America, Somerville, N. J.

[1] *L. J. Giacoletto, "Study of PNP Alloy Junction Transistor from DC Through Medium Frequencies", RCA Review, Vol. XV, No. 4, Dec. 1954.*

[2] *L. J. Giacoletto, "Equipment for Measuring Junction Transistor Admittance Parameters for a Wide Range of Frequencies", RCA Review, Vol. XIV, No. 2, June 1953.*

Resistance Parameter $r_{bb'}$

There is no analytic expression for the equivalent resistance, $r_{bb'}$. Experimentally, however, this extrinsic parameter varies with temperature in much the same manner as does the resistivity of the transistor base material. The $r_{bb'}$ of the 2N77 transistor used in this study was found to vary with temperature up to 50°C in the same manner as material having a resistivity of 4-ohm-*cm*. Practical difficulties prevented measurement of $r_{bb'}$ at temperatures above 50°C. The values of $r_{bb'}$ used in calculations of other hybrid-π circuit parameters at temperatures above 50°C were calculated from the 4-ohm-*cm* curves. Resistivity curves for 0.6-, 1.6-, 4-, and 10-ohm-*cm*, *n*-type germanium (normalized to 25°C) are shown in *Fig. 2*. These curves were derived from those of Herkart and Kurshan,[3] and allow one to determine the variation with temperature of the $r_{bb'}$ of most *a-f*-type *p-n-p* alloy-junction transistors. When the resistivity of the base material is not known the values for 4-ohm-*cm* material may be used in calculations of other hybrid-π parameters. Little error is introduced by the use of these values, because of the manner in which $r_{bb'}$ enters the calculations.

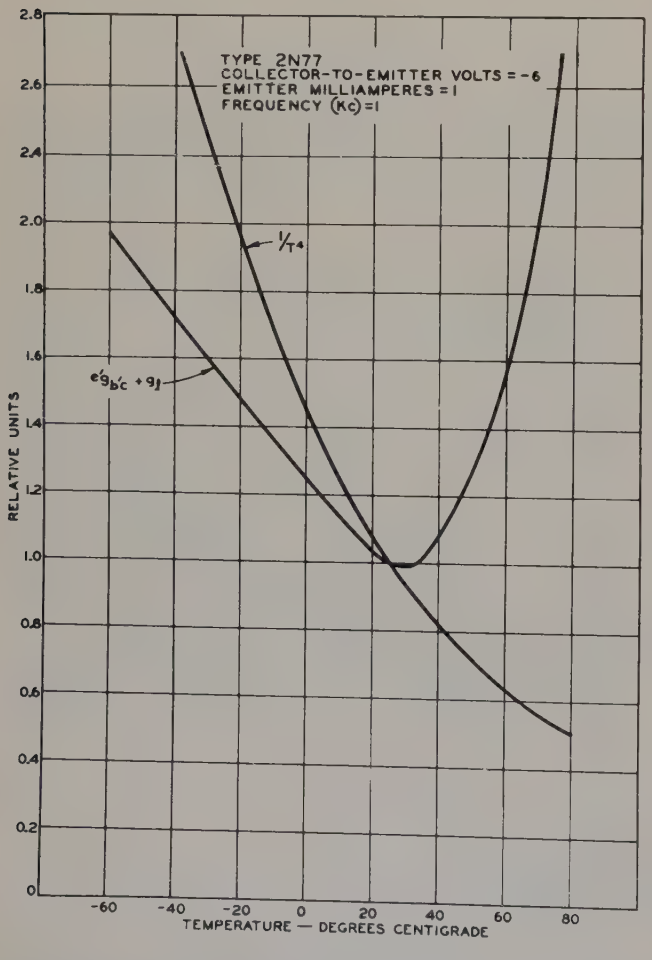


Fig. 3—Variation with temperature (normalized to 25°C) of conductance parameter $e'g_{b'c}$ for RCA-2N77 transistor, and reciprocal of absolute temperature to the fourth power.

Intrinsic Base-to-Collector Conductance Parameter

The conductance between the intrinsic base, *b'*, and the collector is composed of two components in parallel: a temperature-sensitive leakage component g_l and a theoretical component which can be expressed as

$$e'g_{b'c} = -(I_C - I_{CS}) \frac{W_b}{2L_b} \frac{1}{2} \left[\frac{-2 K_e \epsilon_o \mu_n}{\sigma_b V_{ce}} \right]^{\frac{1}{2}} \qquad (1)$$

when I_C is the *d-c* collector current
I_{CS} is the *d-c* collector saturation current
W_b is the base thickness
L_b is the diffusion length for minority carriers in the base
K_e is the relative permittivity of Ge (16)
ϵ_o is the permittivity of free space
μ_n is the electron mobility
σ_b is the conductivity of base material, and
V_{CE} is the applied *d-c* collector-to-emitter voltage

The quantities in Equation (1) which vary appreciably with temperature are I_{CS}, L_b, μ_n, and σ_b. For constant *d-c* emitter current I_E the quantity $(I_C - I_{CS})$ is almost equal to $-\alpha_n I_E$ and, therefore, is practically constant for temperatures where I_{CS} can be neglected. Over the temperature range of −60 to +25°C the electron mobility, μ_n, varies inversely at the 1.6 power of temperature,[4] and the base conductivity σ_b varies approximately as $1/T^2$ (see *Fig. 2*). Over this range, therefore, changes in the quantity in brackets in Equation (1) can be ignored. Because the diffusion length for minority carriers in the base, L_b, varies approximately as the temperature squared,[5] changes in Equation (1) due to variation of L_b greatly outweigh those due to variations of other quantities. At temperatures up to about 25°C, therefore, $e'g_{b'c}$ should decrease very rapidly, very nearly as $1/T^4$, as temperature increases. Above 25°C the minority-carrier lifetime, τ_p, and consequently, the diffusion length, L_b, change slowly with temperature so that $e'g_{b'c}$ should show relatively little variation. Above approximately 50°C, the diffusion length decreases with temperature, with the result that $e'g_{b'c}$ tends to increase.

Figure 3 is a plot of the measured intrinsic base-to-collector conductance, together with one of $1/T^4$ (absolute) normalized to 25°C.

The magnitude of the leakage component g_l at $T = 25$°C, $V_{CE} = 6$ volts, and $I_E = 1$ *ma* was determined by measurement of the intrinsic base-to-collector conductance at zero emitter current,[1] and is in the order of 0.02 micromho. The magnitude of $e'g_{b'c}$ under the same conditions is approximately 0.11 micromho. The measured intrinsic base-to-collector conductance below 25°C, therefore, is practically $e'g_{b'c}$ and above 25°C is the sum of $e\,g_{b'c}$ and the leakage conductance g_l. The theoretical considerations dis-

ıssed in the preceding paragraph indicate that the akage component of $e'g_{b'c}$ should remain substantially nstant between 25 and 50°C. The rapid increase in e measured intrinsic base-to-collector conductance ove 25°C, therefore, suggests that the leakage comnent is very temperature sensitive. Qualitatively, ıe measured variation in intrinsic base-to-collector nductance at temperatures below 25°C is about as pected. Quantitatively, however, it is proportional to $/T^2$ rather than to $1/T^4$ as predicted by theory. This iscrepancy may be due to surface effects which play in important part in minority-carrier lifetime, and hich were not considered in the quantitative deternations.

onductance Parameter e'g$_{ce}$

The collector-to-emitter conductance $e'g_{ce}$ is equal

$$e'g_{ce} = -(I_C - I_{CS}) \frac{1}{W_b} \frac{1}{2} \left[\frac{-2 K_e \epsilon_o \mu_n}{\sigma_b V_{CE}} \right]^{\frac{1}{2}} \qquad (2)$$

As in Equation (1), the temperature-dependent uantities in Equation (2) are the electron mobility, hich varies as $1/T^{1.6}$ from −60°C to about +25°C[4], nd the conductivity of the base material, σ_b, which aries approximately as $1/T^2$ over this temperature ange. The term $(I_C - I_{CS})$, as before, is practically onstant for constant emitter current.

The experimental curve for the conductance $e'g_{ce}$ is iven in *Fig. 4*, together with a plot of $(\mu_n/\sigma_b)^{\frac{1}{2}}$ ormalized to 25°C. It can be seen the $e'g_{ce}$ varies lmost exactly in the manner predicted by theory rom −60 to about +50°C, but then varies in a manner opposite to that predicted. This discrepancy may e due to the fact that the experimental curve for $e'g_{ce}$ was constructed from data which included the eakage conductance g_l and the difference between the

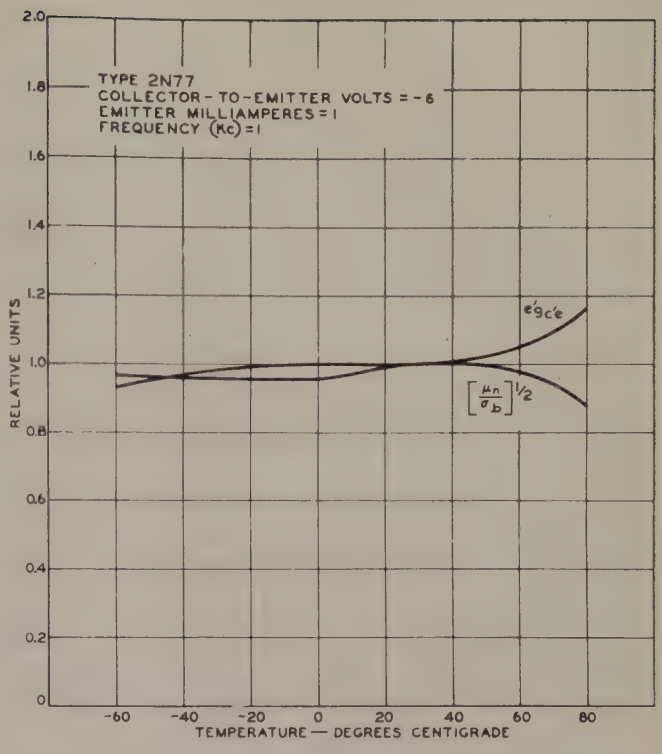


Fig. 4—Variation with temperature (normalized to 25°C of conductance parameter $e'g_{ce}$ for RCA-2N77 transistor, and $(\mu_n/\sigma_b)^{1/2}$

quantities g_{cce} and g_{bce}, both of which showed slight drifts in value with time at elevated temperatures. It may also be due (in part, at least) to the fact that $e'g_{ce}$ does not vary with current exactly as predicted by theory.[1] The experimental variation with temperature of $e'g_{ce}$, however, does not differ significantly from that suggested by theory.

Conductance Parameter e'g$_{b'e}$

The intrinsic base-to-emitter conductance $e'g_{b'e}$ is given closely by

$$e'g_{b'e} = -\frac{q}{kT}(I_B - I_{BS}) \qquad (3)$$

where q is the electron charge (1.6×10^{-19} coulombs)
k is Boltzman's constant (1.38×10^{-23} Joules per degree Kelvin)
I_B is the d-c base current, and
I_{BS} is the d-c base saturation current.

The term I_B in Equation (3) can be replaced by

$$= -I_E(1 - \gamma_{CE}) \qquad (4)$$

where I_E is the d-c emitter current produced by minority carriers, γ_{CE} is the fraction of the total emitter current produced by minority carriers and is equal to

$$\frac{1}{1 + \frac{A_e}{A_b}\frac{\sigma_b}{\sigma_e}\frac{L_b}{L_e}\tanh\frac{W_b}{L_b}} \qquad (5)$$

[3] *P. G. Herkart and J. Kurshan, "Theoretical Resistivity and Hall Coefficient of Impure Germanium Near Room Temperature", RCA Review, Vol. XIV, No. 3, Sept. 1953.*

[4] *M. B. Prince, "Drift Mobilities in Semiconductors I Germanium", Physical Review, Vol. 92, pp 682-687, November 1, 1953.*

[5] *This relation is obtained from the equation $L_b = L_p = \sqrt{D_p \tau_p}$ (see reference 7, p. 314 for equation), where L_b is diffusion length for minority carriers or holes, and τ_p is the hole lifetime. D_p may be calculated from $D_p = \frac{kT}{q}\mu_p$, where the variation of μ_p with temperature is proportional to temperature to the minus 2.3 power[4]. This relation is valid for a wide range in resistivity of germanium. The variation with temperature of the effective lifetime of minority carriers in the base region, τ_p, was calculated from data given in reference 6. This data is for 8 ohm-cm material but similar behavior is expected for 4 ohm-cm material. This data shows that in the temperature range below 25°C, τ_p varies approximately as the fifth power of the temperature. Above 25°C, the variation of lifetime with temperature diminishes sharply and above 50°C it decreases with temperature. Many factors influence the lifetime and not much data is available on the variation with temperature.*

[6] *R. N. Hall, "Physics Review", Vol. 87, pp 387, 1952.*

[7] *W. S. Shockley, Book Electrons and Holes in Semiconductors, D. Van Nostrand Co. 1950.*

A_b and A_e are the areas of the base and emitter, respectively,

σ_b and σ_e are the conductivities of the base and emitter materials, respectively, and

L_b and L_e are the diffusion lengths for minority carriers in the base and emitter, respectively.

For the RCA-2N77 transistor $W_b << L_b$, so that $\tanh W_b/L_b$ is nearly equal to W_b/L_b. By substitution of these terms in Equation (3), therefore, $e'g_{b'e}$ can be expressed as:

$$e'g_{b'e} = \frac{q}{KT} I_e \frac{A_e}{A_b} \frac{\sigma_b}{\sigma_e} \frac{W_b}{L_e} + \frac{q}{KT} I_{BS} \qquad (6)$$

[8] *L. J. Giacoletto, "Power Transistors for Audio Output Circuits",* Electronics, *pp 144-148, January 1954.*

[9] *H. C. Lin, "Temperature Effects in Circuits Using Junction Transistors",* Transistors I, *RCA Laboratories.*

[10] *J. J. Ebers & J. L. Moll, "Large Signal Behavior of Junction Transistors",* Proc. IRE, *Vol. 42, No. 12, Dec. 1954, pp 1761-1772.*

[11] *A. B. Glenn and I. Joffe, "The Effects of Temperature and Frequency on Power Gain and Hybrid Pi Parameters",* TR-1087.

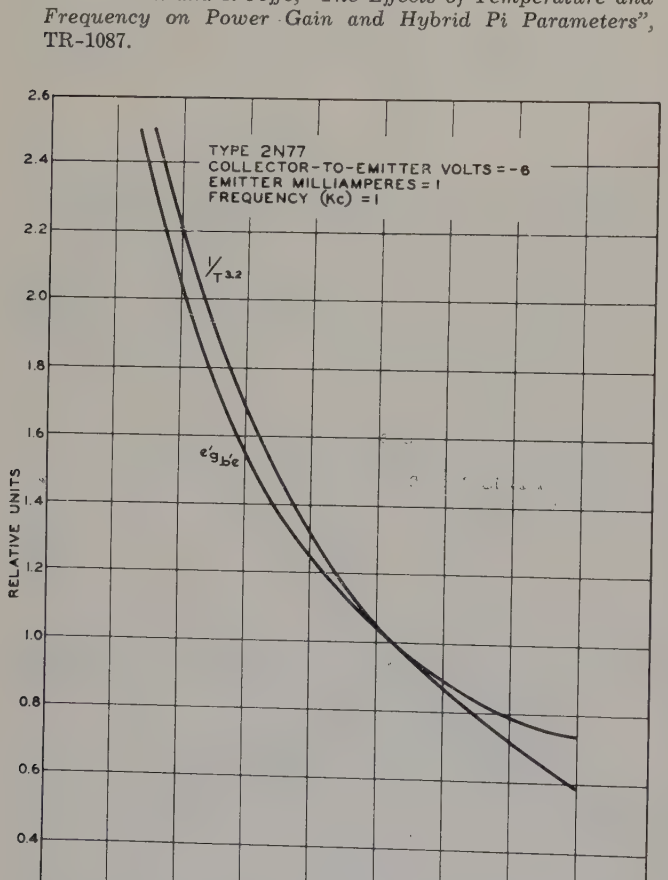


Fig. 5—Variation with temperature (normalized to 25°C) of conductance parameter $e'g_{b'e}$ for RCA-2N77 transistor, and reciprocal of absolute temperature to the 3.2 power.

The orders of magnitude of the numerical values in Equation (6) indicate that the term $(q/kT)\, I_{BS}$ can be neglected for temperatures where I_{BS} is small compared to I_E. Assuming that the ratios A_e/A_b and σ_b/σ_e are constant at temperatures up to about 40°C (see *Fig. 2*), $e'g_{b'e}$ over this temperature range should vary inversely as the temperature times the diffusion length L_e. The variation of minority-carrier lifetime τ_n can be determined (as for $e'g'_{b'c}$) from the electron-mobility factor, μ_n, which varies as $1/T^{1.6}$. The net variation in $e'g_{b'e}$ is then proportional to $1/T^{3.2}$.

The experimental variation of $e'g_{b'e}$ and the curve of $1/T^{3.2}$ are plotted in *Fig. 5*. It is evident that the agreement is excellent. The flattening of the $e'g_{b'e}$ curve at high temperatures can be attributed to the increase in the base saturation current I_{BS} and the falloff in the diffusion length L_e.

Intrinsic Transconductance $e'g_m$

Analytically, the intrinsic transconductance $e'g_m$ is expressed as

$$e'g_m = -\frac{q}{kT}(I_C - I_{CS}) \qquad (7)$$

Because $I_C - I_{CS}$, as previously noted, is practically constant for constant emitter current, $e'g_m$ should vary as $1/T$. The curves in *Fig. 6* show that there is excellent agreement between $e'g_m$ and a plot of $1/T$ normalized to 25°C. The slight separation of the curves at low temperature (−50 to −60°C) is due to a small error in temperature measurement.

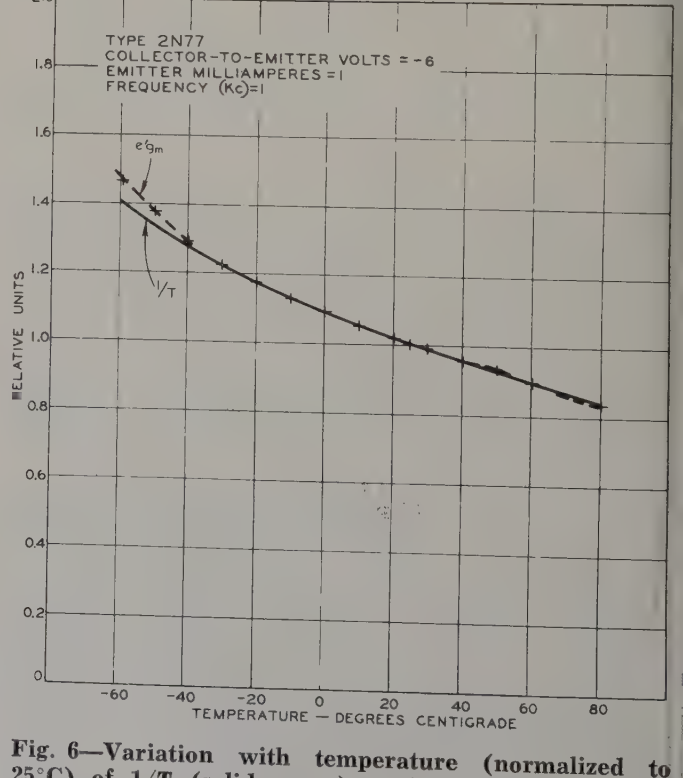
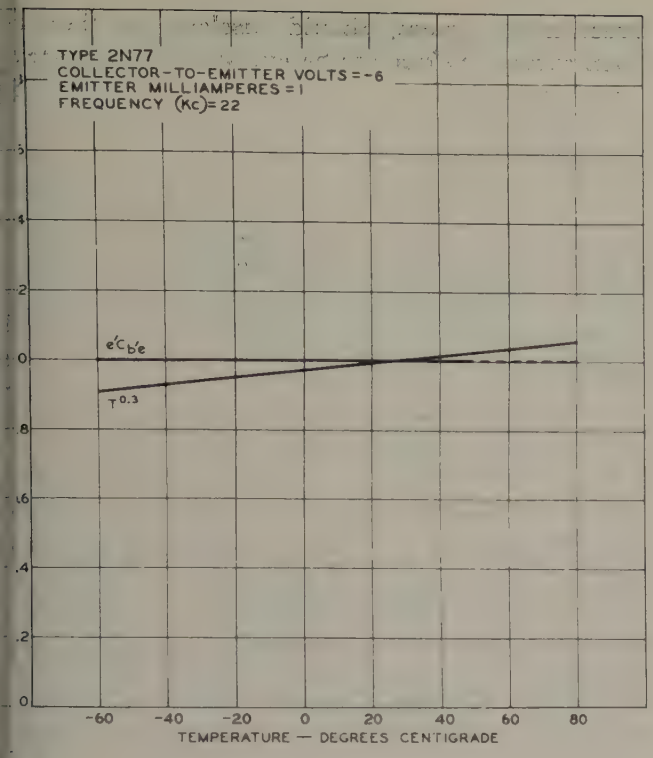


Fig. 6—Variation with temperature (normalized to 25°C) of $1/T$ (solid curve), and measured transconductance parameter $e'g_m$ for RCA-2N77 transistor (crosses).



ig. 7—Variation with temperature (normalized to 5°C) of capacitance parameter $e'C_{b'e}$ for RCA-2N77 ransistor, and $T^{0.3}$.

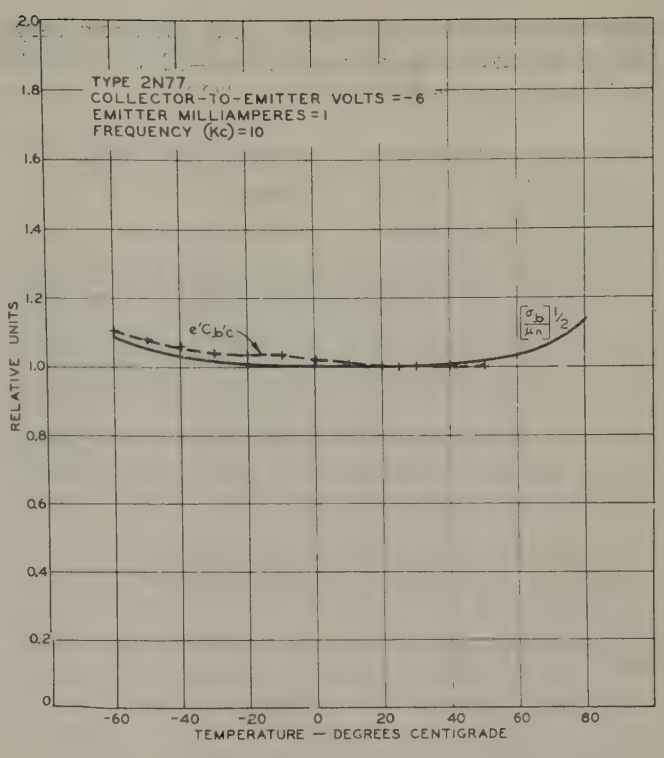

TYPE 2N77
COLLECTOR-TO-EMITTER VOLTS = -6
EMITTER MILLIAMPERES = 1
FREQUENCY (Kc) = 10
RELATIVE UNITS
e'C_b'c
[σ_b/μ_n]^1/2
2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0
-60 -40 -20 0 20 40 60 80
TEMPERATURE — DEGREES CENTIGRADE

Fig. 8—Variation with temperature (normalized to 25°C) $(\sigma_b/\mu_n)^{1/2}$ (solid curve), and measured capacitance parameter $e'C_{b'c}$ for RCA-2N77 transistor (crosses).

ne Capacitance Between The Intrinsic Base And The mitter

The intrinsic base-to-emitter capacitance, $e'C_{b'e}$, is xpressed very nearly as

$$e'C_{b'e} = \frac{q}{kT}(I_E - I_{ES})\frac{W_b^2}{2D_p} \qquad (8)$$

The temperature variables in Equation (8), in addition to T, are the emitter saturation current, I_{ES}, which is negative and temperature-sensitive, but small[8,9], and the hole-diffusion constant, D_p, which varies as $1/T^{1.35}$. Therefore, when the emitter saturation current can be neglected, $e'C_{b'e}$ can be expected to increase as $T^{0.3}$. The experimental variation of $e'C_{b'e}$ and the curve of absolute temperature to the 0.3 power (normalized to 25°C) are given in *Fig. 7*. It is evident that at temperatures below 50°C $e'C_{b'e}$ does not vary in the manner predicted but is, instead, nearly constant ($e'C_{b'e}$ was not measured at temperatures above 50°C). In several type 2N77 transistors the measured value of $e'C_{b'e}$ also remained nearly constant, or decreased slightly. These differences between measured and predicted behavior may be the result of a change in the value of the diffusion constant, D_p, at currents greater than 0.6 milliampere[1].

Capacitance Parameter $e'C_{b'c}$

The intrinsic base-to-collector capacitance, $e'C_{b'c}$ is given by Giacoletto[1] as

$$e'C_{b'c} = \frac{K_e \epsilon_0 A_c}{\left[\frac{-2K_c \mu_n V_{CE}}{\sigma_b}\right]^{\frac{1}{2}}} - (I_C - I_{CS}) \times \frac{W_b}{2D_p}\frac{1}{2}\left[\frac{-2K_e \mu_n}{\sigma_b V_{CE}}\right]^{\frac{1}{2}} \qquad (9)$$

Where A_c is the area of the collector

V_{CE} is the applied d-c voltage between the collector and the emitter, and the other terms are as previously defined.

The temperature variables in Equation (9) are again the electron mobility μ_n, the conductivity of the base material σ_b, the hole-diffusion constant D_p, and the collector saturation current, I_{CS}. Because the variations of these quantities with temperature were previously discussed only the net variation of $e'C_{b'c}$ over the temperature range from −60°C to +80°C will be considered.

For the type 2N77 transistor, the first term in Equation (9) is approximately ten times as great as the second term[1]. Over the temperature range of −60° to +50°C the electron mobility and base conductivity change with temperature in such a manner that the quantities in brackets increase, thereby causing the first term to decrease slightly as temperature is raised. The second term also increases with temperature, but at a smaller rate. Above 50°C, the first term continues to increase while the second term decreases. Therefore, $e'C'_{bc'}$ should vary nearly as σ_b/μ_n.

These quantities are plotted in *Fig. 8*, and show very good quantitative agreement from −60 to +50°C. (*e* $C_{b'c}$ was not measured above 60°C.)

Applicability Of Normalized Curves To P-N-P Type Germanium Alloy-Junction Transistors

Resistance Parameter -$r_{bb'}$

When the resistivity of the base material is known the variation in $r_{bb'}$ can be found from *Fig. 2*. The resistivity of the base material used in most present-day *p-n-p* transistors designed for *af* applications is 2 to 4 ohm-*cm*. It can be seen from *Fig. 2* that for temperatures up to about 60°C there is not much difference in the behavior of $r_{bb'}$ for a fairly wide range of base-material resistivities.

Intrinsic Base-To-Emitter Conductance -$e'g_{b'e}$

Consideration of the quantities contained in Equation 6 suggests that for any *p-n-p* alloy-junction transistor this parameter will vary with temperature in the manner shown by the curves in *Fig. 5*.

Intrinsic Base-To-Collector Conductance

For temperatures below 25°C, the normalized curve for this conductance (shown in *Fig. 3*) should be generally useful because the temperature-sensitive leakage component is comparatively small and because the curve varies qualitatively in the manner predicted by theory. Above 25°C, however, the leakage component has appreciable magnitude, and varies from transistor to transistor, so that quantitative agreement between actual and theoretical values cannot be expected. The portion of *Fig. 3* below and above 25°C, therefore, is only of qualitative interest for *p-n-p* alloy-junction transistors other than type 2N77.

Collector-To-Emitter Conductance -$e'g_{ce}$

The curve for $e'g_{ce}$, shown in *Fig. 4*, varies closely in the manner predicted to about 50°C, and, therefore, should be valid for most *p-n-p* alloy-junction transistors up to that temperature. Further work, including direct measurement, should disclose whether the given curve for $e'g_{ce}$ is to be expected for other transistors above 50°C.

Transconductance—$e'g_m$

Inasmuch as $e'g_m$ varied almost exactly as predicted and does not depend on the geometry and material of the transistor, the curve shown in *Fig. 5* should be valid for all *n-p-n* and *p-n-p* alloy-junction transistors within the restrictions given by Giacoletto in the derivation of the original equation.[1]

Intrinsic Base-To-Emitter Capacitance—$e'C_{b'e}$

As shown in *Fig. 7*, this capacitance did not vary with temperature exactly in the manner predicted, probably because of certain second-order effects which were not taken into consideration. Other studies have shown that the behavior of $e'C_{b'e}$ with temperature varies among transistors of the same type, particularly in the case of transistors designed for *r-f* applications. The curve shown in *Fig. 7*, therefore, is probably of most interest for transistors similar to the RCA-2N77.

Intrinsic Base-To-Collector Capacitance—$e'C_{b'c}$

As shown in *Fig. 8*, this capacitance varied with temperature as predicted to about 50°C. However, other studies,[11] have shown somewhat different results. The results given here, therefore, may be applicable only to type 2N77 transistors.

The experimental results obtained in this study are, in general, in good agreement with those indicated by theoretical considerations for the hybrid-π equivalent circuit. These results, therefore, suggest that the hybrid-π is probably the most useful equivalent circuit for determining transistor performance as a function of voltage, current, frequency, and temperature.

ACKNOWLEDGEMENT

I wish to thank Mr. R. M. Cohen and Mr. L. Giacoletto for their encouragement in writing this paper.

Transistor Heat Sinks and Their Evaluation

CHARLES D. SIMMONS*

It is important in the design of high reliability transistorized equipment that the transistor junction temperatures be kept as low as possible. The junction temperatures will be determined both by the construction of the transistor and by the external heat flow paths provided by the circuit designer. Since the external thermal paths are often highly complex, it is desirable to have a method for measuring the junction temperature of a transistor when operating in its normal environment. This article presents simplified thermal equivalent circuits for the transistor and describes two methods of measuring the junction temperature of a transistor under normal operating conditions. Both of these methods are simply implemented with readily available components.

THE USEFUL life of a transistor is mainly determined by the temperatures to which the junctions are subjected. The processes of transistor deterioration generally result in slow monotonic changes in the parameters so that it is the integrated number of hours at a given junction temperature which is important and it makes little difference whether the heating is the result of storage in high ambient or of heat rise in the transistor due to internal dissipation. The maintenance of reasonable storage temperatures and the efficient removal of internally generated heat are important considerations in the design of long-lived reliable transistorized equipment. This article deals with the removal of heat from an operating junction and the measurement of the efficiency of this heat removal.

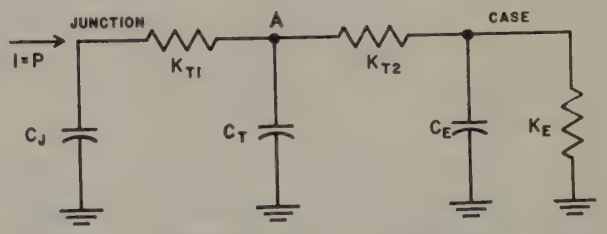


Fig. 1—Thermal equivalent circuit (Small Junctions).

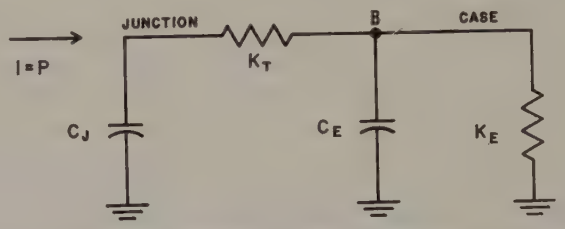


Fig. 2—Thermal equivalent circuit (Medium and Large Junctions).

Electrical Analog

The heat flow path in a transistor may be represented by an electric circuit analog where current represents power, voltage represents temperature, capacity represents thermal capacity, and resistance represents thermal resistance. The thermal characteristics of most transistors are sufficiently linear to allow their representation as constant elements. The equivalent circuit of *Fig. 1* is valid for small, high frequency transistors where the junction thermal capacity, C_J, is small compared to the capacities of the remainder of the transistor. K_{T1}, C_T, and K_{T2} represent a "*T*"-equivalent circuit for the heat flow path between the junction and the case, C_E represents the thermal capacity of the case and heat sink, and K_E represents the thermal resistance from the case to the ambient, T_A. For medium power and power transistors C_T is usually small enough compared to C_J so that the transistor may be represented by the simplified equivalent circuit of *Fig. 2*. Hence K_T represents the total thermal resistance between the junction and the case. K_E and C_E are under the designer's control while the other impedances are internal to the transistor. If the heat sink is a flat plate the value of K_E may be estimated with some degree of accuracy. H. L. Aronson[1] has published some excellent curves which allow the calculation of the thermal resistance of such radiators. C_E may be calculated if the volume of the heat sink is known. These calculations are usually valid only for large heat sinks and inaccuracies occur if the ambient conditions are not well controlled. In general, it is more desirable to place the transistor in its operating environment and measure the thermal properties directly.

Thermal Resistance Measurement

The junction temperature of the transistor operated under steady state power dissipation will be given by:

$$T_J = KP + T_A \qquad (1)$$

where K is the total thermal resistance from junction to ambient. Nature has provided two convenient thermometers in the transistor which may be used to measure the junction temperature. The leakage current of the collector diode under reverse bias, I_{CO}, will

* *Chief Applications Engineer, Lansdale Tube Co. Division of the Philco Corp.*

[1] H. L. Aronson, "Applying Power Transistors to Control", *Control Engineering*, October 1956.

increase exponentially with junction temperature and the voltage drop across the forward biased emitter diode, V_{EB}, will decrease linearly with temperature. If the transistor is placed in its operating environment and the junction temperature is measured first with the transistor non-operating and then operating with a known power dissipation, the first reading will give T_A and the second the T_J of Equation (1). The total thermal resistance may be calculated from Equation (1) as:

$$K = \frac{T_J - T_A}{P} \qquad (2)$$

If the information is required, the same measurement may be repeated with the transistor either mounted on an infinite heat sink or immersed in a constant-temperature oil bath. In either case this measurement will lead to K_T alone. This value may be subtracted from the total resistance of Equation (2) to obtain K_E.

I_{CO} Thermometer

The I_{CO} thermometer shown in *Fig. 3* provides a means of applying a variable steady-state power to the collector junction and also a means for interrupting this power to momentarily sample the I_{CO}. S_1 and S_2 are relay contacts which are driven in tandem. When they are both closed power is applied to the collector. The resistance R_1 will control the emitter current and indirectly the collector current and collector power dissipation. The relay timing is such that S_1 and S_2 are closed for approximately 98% of the time. During the remaining 2% of the time both switches open. The opening of S_1 isolates the emitter circuit so that the only current flowing in the base is the I_{CO}. At the same time the opening of S_2 removes the short across R_2 so that the I_{CO} will show up as a voltage drop across R_2. The scope picture will show a negative pulse with a 2% duty cycle, the amplitude of which is I_{CO}. If the junction time constant is such that the collector diode does not appreciably cool during the sampling time, then the measure of I_{CO} is a measure of the junction temperature under the supplied dissipation.

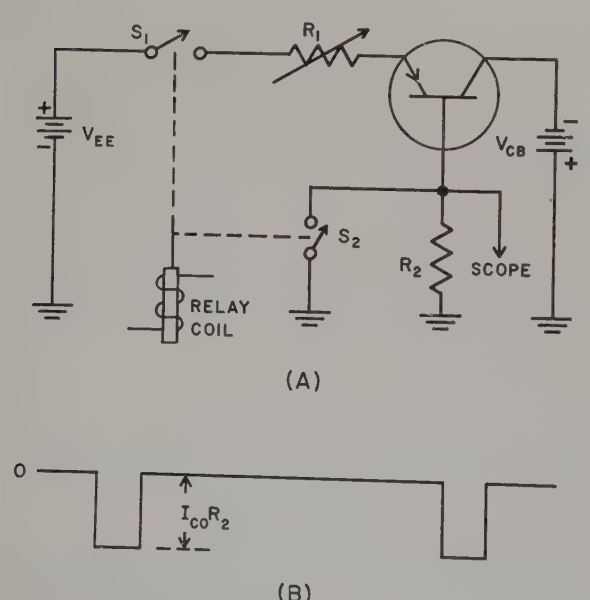


Fig. 3—I_{co} Thermometer (a) I_{co} thermometer circuit (b) Scope presentation.

To use the thermometer the transistor is placed in the operating environment, disconnected from the circuit, and connected to the I_{CO} thermometer. S_1 is left open so that no power is dissipated, and the value of I_{CO} is recorded as read from the scope. This is the I_{CO} corresponding to the ambient temperature. S_1 is then allowed to cycle and R_1 is adjusted so that the power dissipated is similar to that normally dissipated in the stage. The transistor is allowed to stabilize and then I_{CO} is recorded. This value of I_{CO} corresponds to the junction temperature under power. R_2 is adjusted during the experiment so that the drop across it does not exceed a few hundred millivolts. V_{CB} is any convenient voltage within the operating range of the transistor. V_{CB} must not be changed during any part of the experiment. The transistor is next carefully removed from the equipment, mounted in an oven, and connected to the I_{CO} thermometer. The oven must be capable of holding a uniform temperature, the transistor must be shielded from any radiant heating, and the oven should be sealed to prevent external air currents from upsetting the experiment. S_1 is left permanently open and the oven temperature is increased until an I_{CO} equal to the ambient measurement made above is obtained. The oven temperature then is the same as the ambient temperature in the equipment. This temperature is noted and then the oven temperature is raised until the I_{CO} equals the I_{CO} observed under power in the equipment. This corresponds to the junction temperature in the equipment under application of the power which was supplied by the I_{CO} thermometer. These two temperatures and the supplied power may then be substituted in Equation (2) to obtain the actual thermal resistance in the equipment. For measurement of most medium power audio, power transistors, and general purpose alloy junction units a useful cycle is 4 milliseconds for measurement of I_{CO} and 200 milliseconds for application of power.

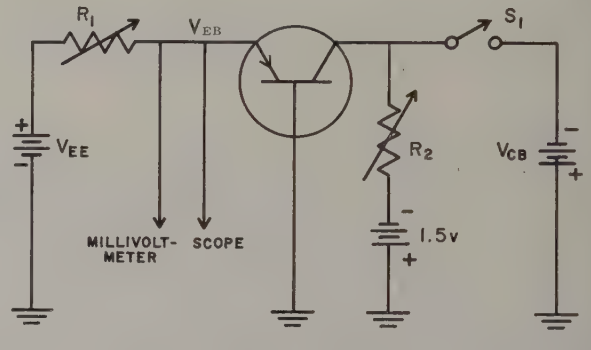


Fig. 4—V_{EB} Thermometer.

his timing can be achieved using a Millisec relay manufactured by Stevens-Arnold Inc., Catalog A-32) driven from a vacuum tube multivibrator. or small high frequency transistors which heat and ol appreciably in 4 milliseconds and for silicon transtors which have very small I_{CO}, the V_{EB} thermomer described below is more useful.

EB Thermometer

The V_{EB} thermometer of *Fig. 4* permits the application of power to the collector junction and the measurement of V_{EB} both before and after the application of the power. The transistor is connected to the thermometer in its operating environment. I_E is adjusted or a current defined below and R_2 is adjusted to apply -0.5 *V* to the collector. V_{EB} is read on the meter. S_1, which is a mercury switch, is then closed and the unit is allowed to stabilize at the new junction temperature. V_{CB} is a voltage in the nominal operating range of the transistor which is many times 0.5 volts

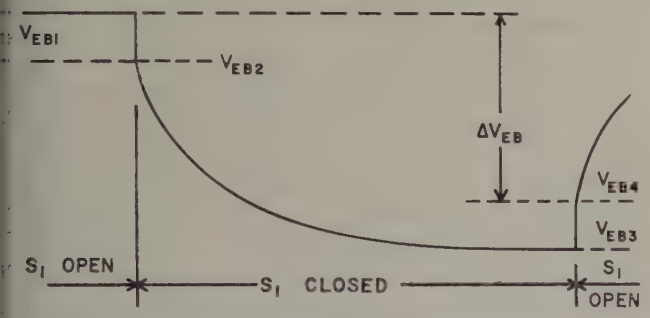


Fig. 5—Scope display—V_{EB} Thermometer

and R_1 is adjusted to apply a power similar to that dissipated in the stage normally. V_{EE} and R_1 are large enough to assure a true current source for the emitter. V_{EE} is preferably greater than 100 volts. I_E must be held constant during all measurements. The scope will display the picture shown in *Fig. 5*. The steep transients in *Fig. 5* are the result of feedback in the transistor and should not be included in the temperature measurement. When the unit has completely stabilized the value V_{EB3}, is recorded from the meter. S_1 is then opened and the feedback voltage ($V_{EB4} - V_{EB3}$) measured with the scope. V_{EB4} may then be calculated. The transistor is then calibrated in the oven by connecting it to the V_{EB} thermometer with S_1 permanently open. The oven temperature is adjusted first for V_{EB1} and then V_{EB4} which correspond to T_A and T_J of Equation (2). These values may be substituted in Equation (2) together with the change in power supplied by the thermometer. This change in power is

$$\Delta P = (V_{CB} - .5)\, I_C$$

so that Equation (2) may be rewritten as:

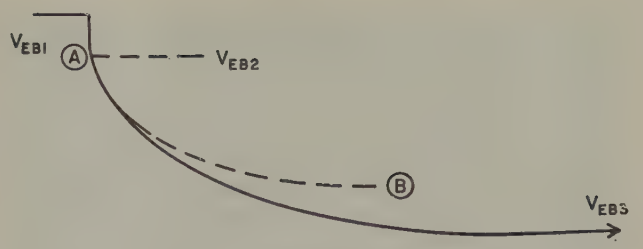


Fig. 6—Initial time constant

$$K = \frac{T_J - T_A}{(V_{CB} - .5)\, I_C} \qquad (3)$$

The V_{EB} thermometer may be used with all transistors. For those types which are normally operated on a large heat sink it is best to mount the unit on a similar heat sink when calibrating the unit in the oven. This is necessary because a small amount of power is dissipated during the calibration. The change in V_{EB} is of the order of a few tens of millivolts so that an accurate, stable meter must be used.

Thermal Time Constant

The equivalent circuits of *Figs. 1* and *2* show that the junction temperature will not rise instantaneously when power is applied. For pulse work where the "on" time is short compared to the time required for the junction to rise to its full temperature, the time constant or the initial rate of rise of junction temperature is often more important than the total thermal resistance. Since V_{EB} is essentially linear with temperature, the portion of *Fig. 5* between V_{EB2} and V_{EB3} gives a picture of the transient thermal response of the junction. Generally, $C_J K_{T1}$ (in *Fig. 1*) or $C_J K_T$ (in *Fig. 2*) is much smaller than the other RC products, but long compared to the "on" time of the pulses encountered in most pulse work. The other time constants will generally be long compared to the repetition rate of such pulses. When these conditions hold *A* and *B* (of *Figs. 1* and *2*) may be considered to be at constant temperature, and the peak junction temperature may be obtained from

$$_{TJ} = K_J P \frac{1 - e^{-Dt_o/t_{c1}}}{1 - e^{-t_o/t_{c1}}} + D_P (K - K_J) \qquad (4)$$

where K_J is either K_T or K_{T1} depending upon which equivalent circuit applies, P is the peak power applied, D is the "on" duty cycle and t_{c1} is the time constant given by $C_J K_J$. The value of this time constant may be derived from the curve of *Fig. 5*. Since we have assumed that the junction time constant is short compared to all the others, the shape of the portion of *Fig. 5* between V_{EB2} and V_{EB3} will be as shown in *Fig. 6*. The dotted line shows the exponential corresponding to the junction time constant. This section of the curve may be plotted on semi-log paper (which gives a straight line plot with slope equal to t_{c1}).

The Spacistor—a New High-Frequency Semiconductor Amplifier

DR. ROBERT PUCEL*, CONRAD LANZA* and DR. HERMANN STATZ*

Several of the shortcomings of the transistor have been overcome with the invention of the Spacistor, a new semiconductor amplifier. This article describes the construction of the Spacistor and its analogy to the tetrode vacuum tube. The action of two new contacts, the injector and the modulator and their associated effects are discussed.

THE SPACISTOR is a new semiconductor amplifying device which shows promise of exceeding the useful frequency range of present-day transistors by a factor of ten. Outwardly, the spacistor is similar in appearance to a tetrode transistor, in that four independent external connections are provided. Structurally, the spacistor will be compact and rugged, leading to reliability. In common with the transistor, it uses no heater and is expected to have a low power consumption, though somewhat higher than that of a transistor. Before describing the factors which give rise to these over-all characteristics, we shall enumerate some of the specific features that will be exhibited by the spacistor.

By far the most important feature is the expected high-frequency operation of the device. This feature is a consequence of the fact that, in the spacistor, the mechanism of current flow is intrinsically faster than the relatively slow, random or diffusion process of conventional transistors and other semiconductor devices. It is confidently expected that this internal mode of operation of the spacistor will respond up to frequencies of 1000 *mc* and higher.

In addition to the enhanced high-frequency response there are three other characteristics which will be particularly welcomed by the circuit designer. The first two are that both the input impedance and the output impedance are very high at low frequencies—of the order of tens of megohms. This will obviously simplify the problem of coupling stages in cascade and in maintaining high-Q interstage circuits. The third characteristic is the very low internal feedback between the output and input terminals. The inherent coupling is small at high frequencies and negligible at low frequencies, since it arises mainly from the capacitance between two very small contacts.

Raytheon Manufacturing Company, Waltham, Massachusetts

For those applications which require operation at high temperatures, the spacistor may provide the means to this end. It appears that the spacistor can be constructed of the new high-temperature semiconductor materials which to date, because of their low carrier "lifetimes," have proven to be unsuitable for construction of the transistor. Lifetime, the average length of time during which the current carriers can exist in the significant region of the semiconductor amplifier before disappearing through recombination with an oppositely-charged particle, is relatively unimportant in the spacistor for two reasons. One of these is the high velocity of the current carriers, *i.e.*, a carrier is subject to recombination during a time much shorter than the lifetime. The other is that only a very small number of oppositely charged particles are present.

As a preliminary to the discussion of the details accounting for the above features of the spacistor, it is worth while to review briefly the reason for the deterioration of transistor gain at high frequencies and the methods used to extend the useful frequency range from the audio frequencies to the vicinity of 200 *mc*. As is well known, the transistor consists of three semiconductor regions called the emitter, base, and collector. The emitter injects charged carriers into the base. These migrate or diffuse to the collector where they enter the external circuit. The primary factor which determines the frequency response is the time taken by the carriers to traverse the base region. As one might expect, this "transit time" depends upon the thickness of the base and the average velocity of the carriers. Since in a transistor there is virtually no electric field in the base region tending to accelerate the carriers to the collector, these carriers are forced to rely on a relatively slow diffusion process.

The first attempts to decrease the transit time were aimed at reducing the base width. This approach was quite successful and base thicknesses of the order of 0.2 mils were attained with a corresponding frequency

esponse in the vicinity of 60 *mc*. This approach, however, reached a practical limit when the resulting devices became too difficult and expensive to manufacture.

Another significant improvement was the use of a graded base. This method incorporates a non-uniform distribution of impurities in the base region which results in a small "built-in" electric field arising from a voltage drop of the correct polarity to aid the carriers in their flow to the collector.

This effect is quite limited, however, since the maximum theoretical voltage drop amounts to only about .35 volt in germanium and an insignificantly higher value in other semiconductors. Since the electric fields produced in this way are so small, the carrier transport process remains essentially one of diffusion with a slight assist from the field. The theoretical enhancement of high-frequency response due to the field is not fully realized in practice; however, the method does lend itself to the attainment of extremely narrow base regions without compromising ruggedness. Units have been reported with useful gains at frequencies in the vicinity of 500 *mc*, which figure represents the present upper limit for transistors.

Having briefly considered the efforts made to improve the transistor, let us now turn to a discussion of the radically new approach upon which the spacistor is based. As is well known, when an ordinary semiconductor junction is biased by a battery in its reverse direction, the high-resistance connection, a substantial electric field is established on either side of the junction. It is this fact upon which the expected high-frequency response of the spacistor rests. For example, using a typical reverse bias of 200 volts, an enormous electric field of the order of 100,000 to 150,000 volts/cm is produced near the junction. By an appropriate choice of impurity densities in the semiconductor, the region of the high electric fields can be made to extend over a region as long as three mils.

In the spacistor, current carriers are injected into this high-field region from an independent electrode. Under the influence of this field, they are swept toward one of the junction electrodes with velocities of the order of ten million centimeters per second. Since the carriers are injected somewhere near the middle of the high-field region, they need travel only about two to three thousandths of a centimeter. The gain is expected to decrease rapidly at frequencies of the order of the reciprocal transit time which, using the above figures, would correspond to the frequency range between 1000 and 10,000 *mc*. Thus, by utilizing the high fields that can be produced in the vicinity of a reverse-biased junction, one not only can reduce the transit time but can also completely eliminate the need for a thin base region.

Fig. 1a is a schematic diagram of the spacistor with its bias circuits and load. As indicated, the spacistor itself consists simply of a diode junction *J*, which is reverse-biased by voltage source V_d in the load cir-

Experimental assembly of the "spacistor," is shown alongside an ordinary pin.

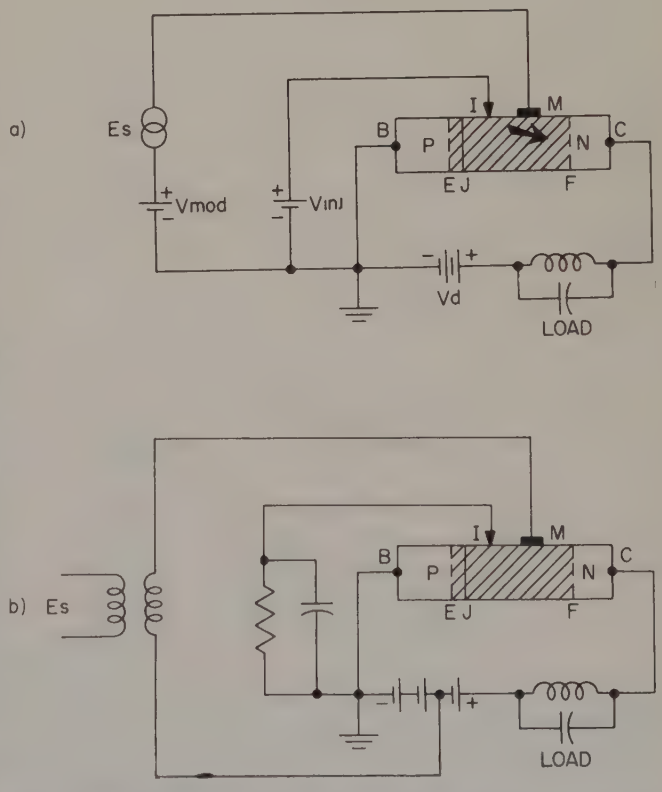


Fig. 1—a) Diagram of the Spacistor, shown with separate bias sources. b) A practical bias connection for the Spacistor.

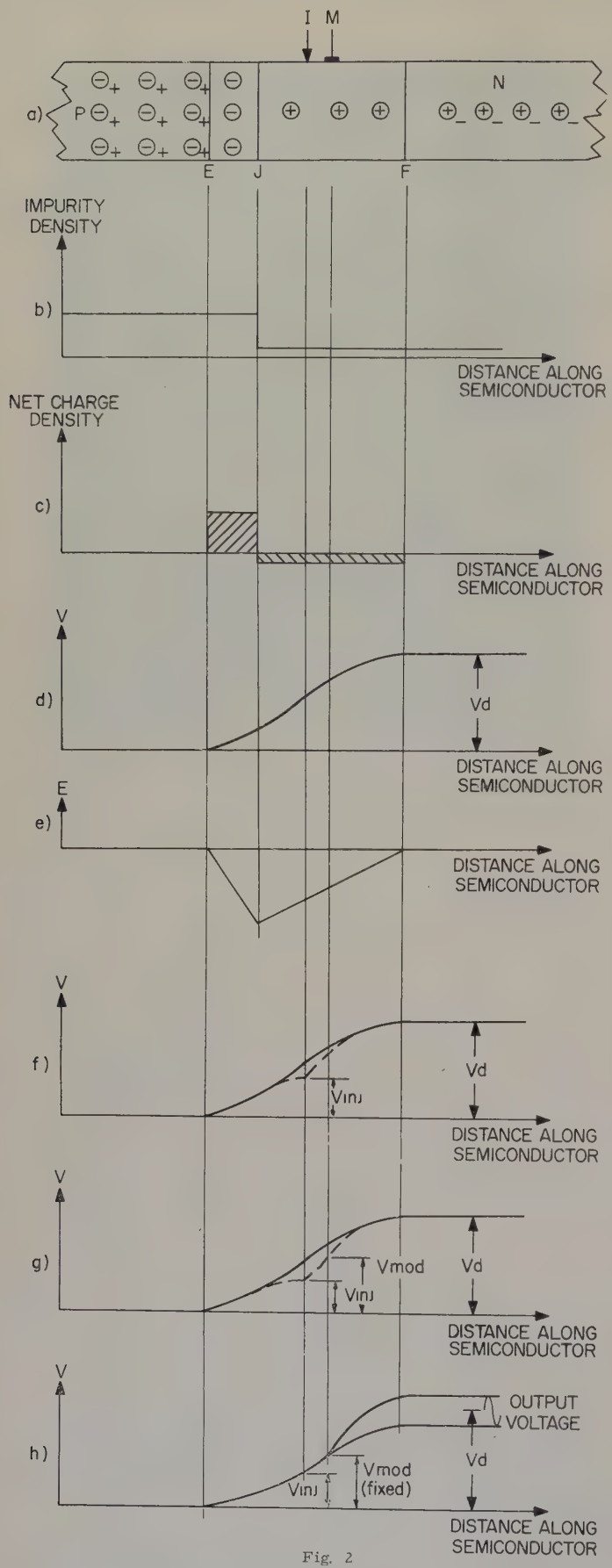


Fig. 2

Fig. 2—a) Diagram of semiconductor. b) Impurity density. c) Net charge density. d) Potential profile. e) Field intensity. f) Potential profile with biased injector present. g) Potential profile with biased injector and modulator present. h) Potential profile showing shielding effect of modulator.

cuit. The region of the high electric fields is shown by the shaded area *EF*. Two electrodes *I* and *M* are connected to the surface of the semiconductor in this region. Contact *I* is the injecting contact or injector and is so biased by the source V_{inj} that electrons are forced into the high field from the source. The electrons move rapidly to the *n*-region of the diode, as indicated by the arrow. As soon as the electrons reach the boundary of the *n*-region, they effectively have reached the external circuit since the bulk of the *n*-region simply acts as a low resistance in series with the load. The electrons continue through the load, the voltage source V_d, and back to the injector. As the electrons flow from the injector to the *n*-region, they pass by the modulating contact or modulator *M*. The signal source E_s is connected to the modulator in conjunction with a bias source. The modulating contact modifies the potential of the semiconductor directly under itself and this effect is felt to a considerable extent even under the injector. Since the potential difference between the injector and the underlying semiconductor is thereby modified according to the applied signal, the injected current, which is also the load current, is modulated.

The spacistor can be shown to have a very close physical and electrical analogy to a tetrode tube. The injector acts as the cathode, the modulator serves as the control grid and as will be shown, also behaves as the screen grid, and the *n*-region plays the role of the anode. For reasons to be described below, the modulator draws no signal current, hence imparting a high input impedance to the device.

Having described the general roles of the various component parts of the spacistor, let us now consider in greater detail their particular characteristics and design. First under consideration is the formation of the high-field or space-charge region. This can be explained with the aid of *Fig. 2*, which shows the region of interest on an enlarged scale. Letters *E* and *F* indicate the boundaries of the space-charge region and correspond to the same letters shown in *Fig. 1a*. Within this region is the semiconductor junction *J*. Also illustrated in this highly simplified sketch of the semiconductor are the neutral *p*- and *n*-regions, the space-charge region, and an indication of the charges contained in each.

Before the application of a reverse-bias voltage, the *p*- and *n*-regions extend almost to the junction, and are formed by the introduction of particular types of impurity atoms during the growth of the crystal. The relative densities of these impurities are shown in *Fig. 2b*. The circled charges in *Fig. 2a* represent ionized atoms which are fixed in position, being bound in the lattice of the semiconductor. The uncircled plus and minus signs indicate mobile positive and negative charges, or holes and electrons respectively, which are free to move about in the semiconductor.

In the neutral *p*-region the negatively charged atoms are neutralized by an equal number of holes and, similarly, in the neutral *n*-region the positively

charged atoms are neutralized by electrons. Between these two regions lies the space-charge region. It is this region which is of interest. When the diode is reverse-biased, very little current flows and virtually all of the applied voltage is dropped across the junction. This creates an electric field which causes the mobile carriers to move out of the junction area. Since the neutralizing carriers have been swept out of this small area, the remaining fixed ionized atoms now constitute a net charge on either side of the junction. This charge is indicated by the shaded area in *Fig. 2c*. Note that the mobile carriers are depleted for a greater distance from the junction in the part of the crystal which has the least impurity density. The spreading of the space charge is such that equal numbers of unneutralized impurity atoms exist on both sides of the junction. As the applied voltage is increased, more carriers are removed and the space-charge area widens. *Fig. 2d* shows a typical distribution of potential through the space-charge region for a particular bias. The electric field corresponding to this potential is shown in *Fig. 2e*.

It was found experimentally that an ordinary pointed tungsten wire could be used to inject electrons into the space-charge region when it is biased negatively with respect to that region. In *Fig. 2f*, the dashed line represents the potential along a line passing through the injector point. The solid line depicts the potential along a parallel line a short distance beneath the surface. It is seen that the potential is disturbed only in the immediate vicinity of the point.

After establishing a stream of electrons in the space-charge region, the next step is to cause the amplitude of this current to be varied in accordance with an impressed signal. This is accomplished with the aid of a second contact positioned very close to the injecting contact. The relative position of these contacts and the resultant potential distribution due to biases applied to them are shown in *Fig. 1a* and *2g*, respectively. Since the modulator and injector contacts are very close, a change in potential of the semiconductor under the modulator is accompanied by a similar change under the injector. Since the injector is maintained at a fixed potential relative to terminal *B*, a change in potential of the underlying semiconductor will result in a change in potential difference between the semiconductor and this point, thereby modifying the magnitude of the injected current. In this way the modulator acts as a control contact similar to a grid in a vacuum tube.

In contrast to the injector, it is desired that the modulating contact pass no signal current. This dictates that the modulator be a small *p*-type contact, biased in reverse as shown in *Fig. 3*. The electrical characteristic of such a contact resembles that of conventional junction. In *Fig. 3*, the voltage shown is the difference between the potential of the *p*-type modulator contact and the underlying space-charge region. With a reverse bias, only a very small operating bias current flows. When the signal is superimposed upon the operating bias, the injected current is modulated as discussed above. However, as seen from *Fig. 3*, no alternating current is drawn by the signal source. It is this property that is responsible for the very high input impedance of the device. For devices fabricated to date, values of input impedance of about 30 megohms have been measured at audio frequencies.

The modulator has another important function. When a signal current flows in the output circuit, the resulting load voltage fluctuations cause variations in the potential profile in the space-charge region. These can change the potential difference between the injector and the underlying semiconductor. This latter phenomenon is prevented by the shielding action of the modulator as can be seen by reference to *Fig. 2h*. This diagram shows the potential variation at the surface along a line passing through the two contacts. The modulator is held at a fixed operating potential by an external bias and is situated between the load and injector terminals, being much nearer to the latter. It "clamps" the potential distribution in the semiconductor in the region between itself and the injector so that the load variations are absorbed elsewhere in the space-charge region. Thus, the injected current is not affected by load voltage fluctuations. This shielding results in a very high output impedance for the device. Values of output impedance of the order of 30 megohms have been measured at audio frequencies.

Since the spacistor requires very little signal input power and possesses a high output impedance, it is convenient and meaningful to express its amplifying capabilities in terms of the degree of control which the modulator exerts on the injector current, just as in the analogous situation of the tube tetrode. This measure of control, called transconductance, is the change in injector current per unit change in modulator voltage when the load voltage is fixed. As may be expected, transconductance is strongly dependent

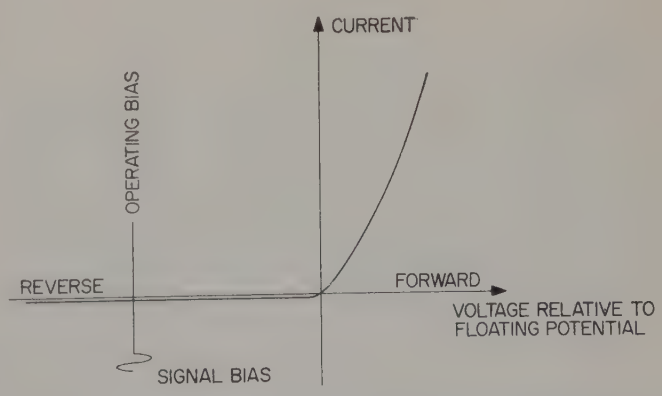


Fig. 3—Characteristic curve of modulator contact showing typical operating bias and superimposed signal.

on the spacing between the injector and modulator contacts, and is also somewhat dependent on the injected current. For contact spacings of the order of one-half mil and injector currents of about 1.5 milliamperes, values of transconductance of 100 microamperes per volt have been measured. Other geometries under consideration are expected to raise this figure by at least a factor of ten.

The diagram shown in *Fig. 1a* was drawn with three separate bias sources for the sake of clarity. *Fig. 1b* is an example of how one bias source can be made to suffice while providing a stable quiescent injector current.

The measurements mentioned above were made at low frequencies while the device was still in the micromanipulator or experimental stage of its development. Units now being fabricated will be subjected to high-frequency measurements. One of the factors which will influence the performance at high frequencies is the capacitance between the modulator and the ground. This consists of the capacitance between the modulator and injector contacts and between the modulator and the *p*-region of the semiconductor. Although the spacing between the contacts is small, so are the respective areas presented by the contacts. Furthermore, the spacing between the modulator and the *p*-region is large because of the wide space-charge region. For the same reasons, the output and feedback capacitances should also be very small. It is estimated that the resulting interelectrode capacitances will be of the order of 1 $\mu\mu f$.

A long list of possible applications for a high-frequency semiconductor device will occur to the reader. The authors wish to point out, however, that since the spacistor eliminates some of the coupling and loading problems it should be considered by circuit designers even for low-frequency applications.

A final note of caution should be made at this point concerning availability. The device described above is still in the research stage. Although a large effort is being made to complete its development as soon as possible, it is estimated that a minimum of three years will be required before the spacistor reaches production.

Flow Graph Analysis Of Transistor Circuits

T. P. SYLVAN*

The techniques of flow graph analysis can be used to great advantage in solving many problems of transistor circuit design. In particular, flow graph analysis may be used for calculation of the gain of amplifier stages, calculation of impedances of complex circuits, or transformation from h-parameters to z or y-parameters. In such problems, flow graph analysis usually results in considerable savings of the time and effort required in obtaining solutions. The major operating rules of flow graph analysis are presented and examples of the application of these rules in typical transistor circuit design problems are given.

INTRODUCTION

THE SMALL-SIGNAL linear analysis of complex electrical networks is one of the most time-consuming tasks faced by the circuit designer. Even with the use of such techniques as matrix analysis the designer usually must go through several operations involving large, complicated algebraic expressions to arrive at final design equations. This is particularly true in the case of transistor circuit analysis where more complicated equivalent circuits are involved and the non-unilateral nature of the transistor makes it necessary to consider the effects of feedback and interaction between stages.

Frequently the amount of work required to arrive at the final design equations may be simplified by the use of appropriate initial approximations. However, to be fully effective this technique requires considerable experience and judgment on the part of the circuit designer and is prone to serious errors. The safest way to arrive at realistic approximations is to carry out an exact analysis and make all approximations on a purely algebraic basis from the final design equations.

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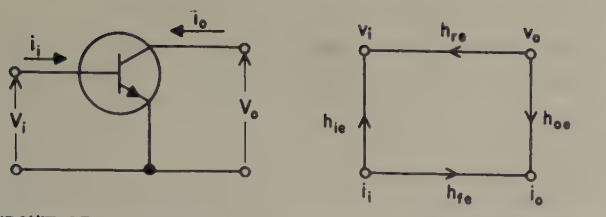


(A) CIRCUIT REPRESENTATION (B) FLOW GRAPH REPRESENTATION

Fig. 1—Flow graph representation of common emitter h-parameters.

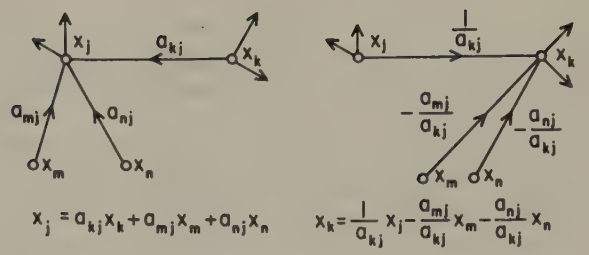


Fig. 2—Rule 1—Branch inversion of a flow graph with related equations.

Thus, what is most needed to simplify the work of the circuit designer is a technique which will permit the derivation of the required final design equations from the basic design information with a minimum of intermediate work. The new technique of linear flow graph analysis proves to be nearly ideal in this respect for a wide variety of circuit design problems.

Much of the original work of developing the techniques of linear flow graph analysis has been done by S. J. Mason of M.I.T.[1, 2]. Indeed, much of the current success of linear flow graph analysis may be ascribed to Mason's versatile rule for deriving the gain of an arbitrary flow graph[2].

FLOW GRAPHS

A *flow graph* is a multiple set of nodes connected by directed branches. The basic nature of a flow graph is essentially a topological relationship, but operationally a flow graph may be assigned properties and operations of functional mathematical relationships. We shall consider here only the applications of linear flow graphs which are assigned properties of linear algebraic equations. The reader should be aware, however, that linear flow graph analysis is only one special technique in a very broad and still not fully explored field.

As a first illustration of possible applications of flow graphs we shall consider the small signal hybrid or *h*-parameters of a transistor. These parameters are defined by the set of equations;

$$v_i = h_{ie}i_i + h_{re}v_o \qquad (1a)$$

$$i_o = h_{fe}i_i + h_{oe}v_o \qquad (1b)$$

Here the *h*-parameters are the common-emitter *h*-parameters and the currents and voltages are the small-signal currents and voltages corresponding to *Fig. 1a*. The notation used is consistent with IRE standards[3].

Fig. 1b shows the flow graph representation of Equation (1). The variables of the equation (v_o, v_i, i_o, i_i) are associated with the nodes of the flow graph while the constants (h_{ie}, h_{fe}, h_{re}, h_{oe}) are associated with the branches. The quantity associated with a particular node is called the *node signal* while the quantity associated with a particular branch is called the *branch gain*. A *source* is defined as a node having only outgoing branches while a *sink* is defined as a node having only incoming branches. A *common node* is a node which is neither a source nor a sink, *i.e.* a node having both outgoing branches and incoming branches. In *Fig. 1b* it is seen that the node signals v_i and i_o correspond to sinks and are also considered the dependent variables of Equation 1. It is also seen that the node signals v_o and i_i correspond to sources and are considered the independent variables of Equation 1. Thus for any flow graph, node signals at sources may be considered as independent variables, node signals at sinks may be considered as dependent variables, and branch gains may be considered as constants in the equivalent linear equations. In general the roles of nodes as sources or sinks may be interchanged just as the roles of independent or dependent variables may be interchanged in linear equations by redefinition and algebraic manipulation. The equivalent process for flow graphs is termed *branch inversion* and is illustrated in *Fig. 2*. Here it is desired to change the direction of the branch between nodes j and k. A rule for this process may be derived by writing the equivalent equation for the flow graph and solving for the node signal x_k as shown in *Fig. 2*.

Rule 1—Branch Inversion

To invert a branch which is initially directed from a source k to a node j the new branch from j to k is assigned a branch gain $1/a_{kj}$ which is the reciprocal of the original branch gain a_{kj}. In addition, all branches which terminated at node j are made to terminate at node k and the original gains of each of these branches are multiplied by the factor $-1/a_{kj}$.

Note that for the above rule to hold it is necessary that initially node k be a source, but it is not necessary that node j be a sink. The transformation results in node j becoming a source and node k no longer being a source. The reader may check the above rule by performing a second inversion with the same branch to restore the original form of the flow graph.

[1] Feedback Theory—Some Properties of Signal Flow Graphs, S. J. Mason, *Proceedings of the I.R.E.*, September 1953, p. 1144.
[2] Feedback Theory—Further Properties of Signal Flow Graphs, S. J. Mason, *Proceedings of the I.R.E.*, July 1956, p. 920.
[3] IRE Standards on Letter Symbols for Semiconductor Devices, *Proceedings of the I.R.E.*, July 1956.

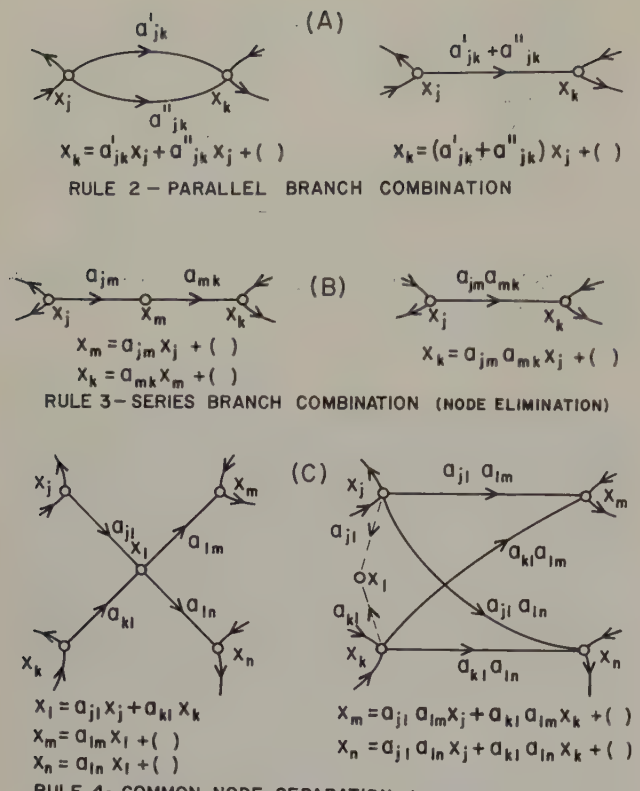

(A)
RULE 2 – PARALLEL BRANCH COMBINATION
(B)
RULE 3 – SERIES BRANCH COMBINATION (NODE ELIMINATION)
(C)
RULE 4 – COMMON NODE SEPARATION (BRANCH SPLITTING)

Fig. 3—Elementary operations with flow graphs.

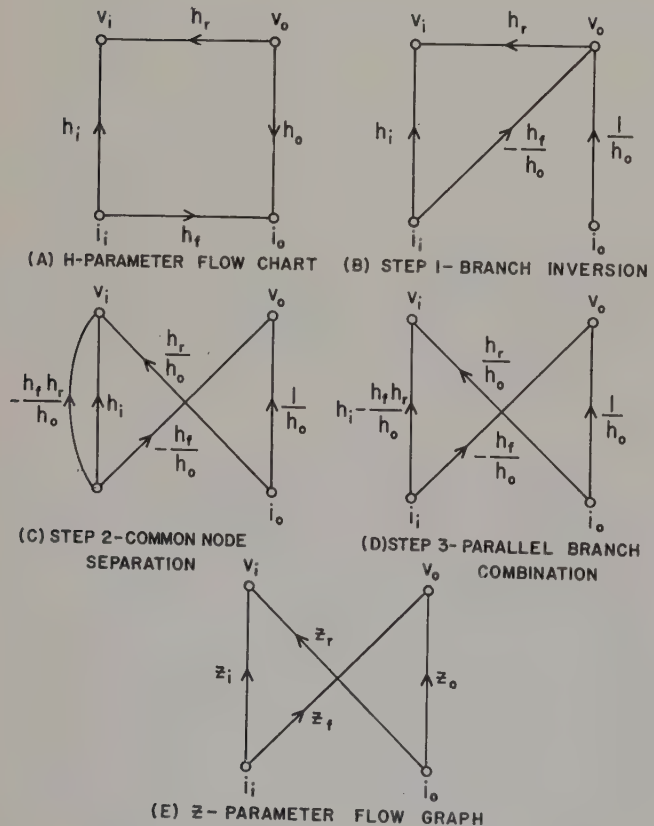

(A) H-PARAMETER FLOW CHART
(B) STEP 1 – BRANCH INVERSION
(C) STEP 2 – COMMON NODE SEPARATION
(D) STEP 3 – PARALLEL BRANCH COMBINATION
(E) z – PARAMETER FLOW GRAPH

Fig. 4—Derivation of z-parameters in terms of h-parameters.

A number of elementary operations with flow graphs are summarized in *Fig. 3* together with the algebraic equations from which they are derived. These operations are frequently useful in simplifying a flow graph. In particular *Figs. 3b* and *3c* present methods for elimination of a node which corresponds to the elimination of a variable in the set of related equations. Note, however, that the node can be separated from the common branches without being eliminated from the flow graph (dotted lines in *Fig. 3c*). The operations indicated in *Fig. 3* may be applied any number of times in any sequence to achieve simplification of a flow graph. When working with flow graphs for the first time it is wise to proceed step by step to avoid errors, but with practice it will be found that many operations can be combined, resulting in very rapid manipulation of the flow graph.

As an example of the rules which have been given, let us consider the calculation of the *z*-parameters of a transistor in terms of the *h*-parameters. The *z*-parameters are defined by the set of equations:

$$v_i = z_i i_i + z_r i_o \tag{2a}$$

$$v_o = z_f i_i + z_o i_o \tag{2b}$$

Here we consider the general case; common base, common emitter, or common collector, so the second subscript on the *z*-parameters is not used. The step by step manipulation of the flow graph is shown in *Fig. 4*. Here we start with the flow graph representing the *h*-parameters and note that in the *z*-parameter representation v_o is a sink and i_o is a source so that we first perform a path inversion between v_o and i_o. When this has been done (*Fig. 4b*) v_o is still not a sink. We may obtain v_o as a sink by a branch splitting operation similar to *Fig. 3c*. Note, however, that in this case we wish to retain v_o in the flow graph. Our final step is the combination of the parallel branches between v_i and i_i (*Fig. 4c*) giving us the result shown in *Fig. 4d*. This figure corresponds to *Fig. 4e* which is the flow graph representation in terms of the *z*-parameters. We may then equate the branch gains of the corresponding branches in the two flow graphs giving:

$$z_i = h_i - \frac{h_f h_r}{h_o} \tag{3a}$$

$$z_r = h_r/h_o \tag{3b}$$

$$z_f = -h_f/h_o \tag{3c}$$

$$z_o = 1/h_o \tag{3d}$$

This example makes the technique of flow graph analysis appear somewhat more involved than need be. After some practice it should be possible to write out only the first step (*Fig. 4b*) and obtain the final equations directly from this flow graph.

If the techniques of flow graph analysis were confined to the preceding operations their usefulness would be quite limited. Although some of the more simple flow graphs can be reduced to the desired form

by these operations in general this can not be done. Feedback loops in the flow graphs are usually encountered which cannot be reduced by these simple techniques. It is for this reason that Mason's general rule[2] for determining the relationship between any source and any sink provides a great extension in the utility of flow graph analysis.

Before stating this rule several definitions must be given. A *forward path* is a progressive sequence of branches from source to sink in which no node is encountered more than once. A *feedback loop* is a progressive sequence of branches that forms a closed path along which each node is encountered once and only once per cycle. The *path gain* (*loop gain*) is the product of branch gains along that path (loop). The *gain of a flow graph* from any source j to any sink k is the ratio of the corresponding node signals x_k/x_j.

Rule 5—The General Gain Expression

The gain of a flow graph from any source j to any sink k is expressed in terms of a quotient. The denominator of this quotient is called the determinant, Δ, of the flow graph and is equal to unity plus a sum of terms equal to the loop gain products of all possible sets of non-touching feedback loops. These terms are positive if the number of feedback loops in the set is even and negative if the number of feedback loops in the set is odd. The numerator of the general gain expression is formed by the sum of all the path gains from source j to sink k. Each of these path gains is multiplied by a factor which is the same as the determinant of the general gain expression except that each term is eliminated which contains the loop gain for any feedback loop which touches the particular forward path. A sufficient condition for any two feedback loops or one feedback loop and a forward path to be touching is that they share one common node.

As an example of the application of this rule consider the flow graph shown in *Fig. 5*. It is seen by inspection that there are two forward paths from source j to sink k. The path gains for these two paths are:

$$G_1 = a_1a_4a_9$$

$$G_2 = a_5a_6a_8a_9$$

There are three feedback loops which have loop gains of:

$$T_1 = a_2$$

$$T_2 = a_3a_4$$

$$T_3 = a_6a_7$$

Using the rule given above the gain of the flow graph is:

$$\frac{x_k}{x_j} = \frac{(1-T_3)\,G_1 + (1-T_1)\,G_2}{1-T_1-T_2-T_3+T_1T_3+T_2T_3} \qquad (4)$$

Here it will be noted that the sets T_1T_2 *and* $T_1T_2T_3$ are not present in the denominator since feedback loops T_1 and T_2 are touching. Likewise all terms containing T_1 and T_2 are eliminated from the factor multiplying G_1 since both of the feedback loops T_1 and T_2 touch the forward path G_1.

As a practical example of the application of the techniques of flow graph analysis let us consider the problem of deriving the h-parameters for two cascaded transistor stages. Using the same notation as that of *Fig. 1* denote all parameters associated with the first transistor by single primes and all parameters associated with the second transistor by double primes. The parameters associated with the total circuit will be unprimed. If the two stages are cascaded there will be two additional equations to be satisfied:

$$v'_o = v''_i \qquad (5a)$$

$$i'_o = -i''_i \qquad (5b)$$

It is obvious in *Fig. 6* how these additional relationships are added to the flow graph. It is important to

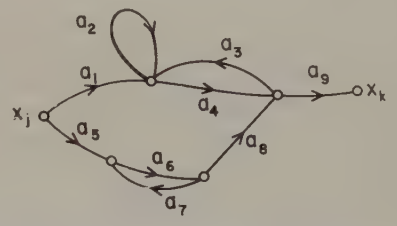


Fig. 5—A flow graph with three feedback loops.

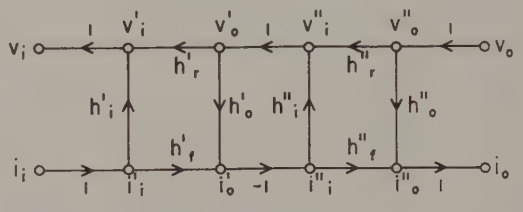


Fig. 6—Flow graph representation of two cascaded transistor stages.

note that the new branch between v'_o and v''_i must be directed from v''_i to v'_o since v''_i is originally a sink and v'_o is a source. Directing the branch from v'_o to v''_i would cause an error in the functional relationship of v''_i which would be equivalent to writing the equation:

$$v''_i = h''_i i''_i + h''_r v''_o + v'_o$$

which is obviously in error since it contradicts the defining equations for the h-parameters. Similar comments apply to the branch added between i''_i and i'_o. It can be seen that there is only one feedback loop in this graph which has a loop gain of $-h'_o h''_i$. The h-parameters for the complete circuit may be obtained simply by writing the gain for each of the forward paths of the flow graph.

$$h_i = \frac{v_i}{i_i} = \frac{h'_i(1 + h'_o h''_i) - h'_f h''_i h'_r}{1 + h'_o h''_i} \quad (6a)$$

$$h_r = \frac{v_i}{v_o} = \frac{h'_r h''_r}{1 + h'_o h''_i} \quad (6b)$$

$$h_f = \frac{i_o}{i_i} = \frac{-h'_f h''_f}{1 + h'_o h''_i} \quad (6c)$$

$$h_o = \frac{i_o}{v_o} = \frac{h''_o(1 + h'_o h''_i) - h''_r h'_o h''_f}{1 + h'_o h''_i} \quad (6d)$$

It is also possible to write the gain from any node to any other node in the flow graph even though these nodes are not a source and a sink. In this respect it is important to note that any node signal can be transferred to a sink merely by adding an outgoing branch from the original node and assigning the branch a gain of unity. If one node is not a source, however, the gain expression can not be applied. In some cases one of the nodes may be transformed to a source by means of a branch inversion. However, if the flow graph contains only one source a simple method for determining the gain between any two nodes is possible. Thus if it is desired to find the gain between any node j and any node k in a flow graph having a single source m, simply calculate the gain x_k/x_m from m to k and the gain x_j/x_m from m to j and divide the first gain by the second gain to obtain the gain x_k/x_j from j to k. Note that when using this method it is unnecessary to write out the determinent of the flow graph since this term cancels out upon dividing one gain by the other.

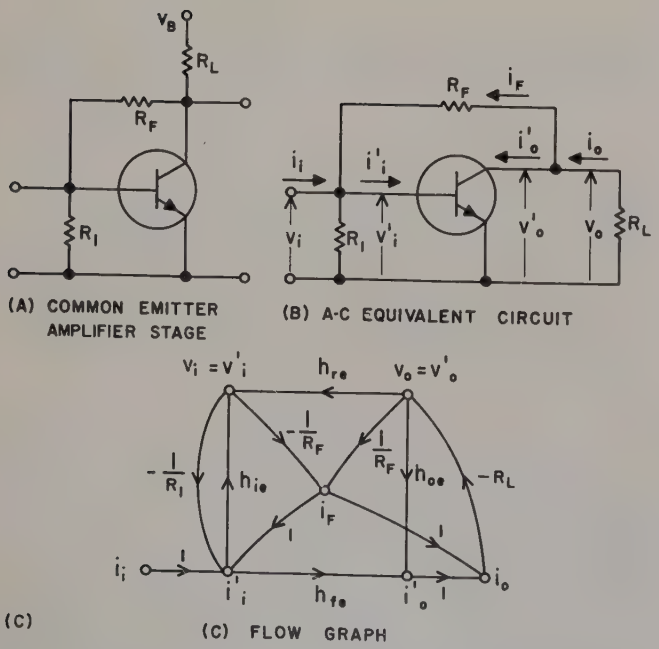


Fig. 7—Analysis of a common emitter amplifier stage.

Before any of the above rules of the flow graph analysis can be applied it is of course necessary to construct a flow graph which represents the functional relationships involved in the circuit under consideration. A completely general method for doing this can not be given, since for any particular circuit there are a large number of possible equivalent flow graphs. The techniques for proceeding from circuit to flow graph are somewhat of an art but can easily be developed through practice. However, a few simple guiding principles can be given to aid in this process:

(1) The final flow graph should contain only one source if a full solution is to be obtained. Construction of the flow graph can thus be regarded as a step-by-step elimination of all sources but one from the flow graph. A source is eliminated by utilizing pertinent functional relationships from the circuit to add incoming branches to that source.

(2) Any of the circuit variables, voltages or currents can be added to the flow graph as desired. Nodes which are superfluous to the analysis will be obvious in the flow graph and can easily be eliminated.

(3) As a check for errors in the flow graph it is to be noted that every path between any pair of nodes should have the same dimensions for the path gain. Similarly, every loop gain should be dimensionless.

(4) In general the form of the flow graph has no similarity to the form of the circuit from which it was derived except for those parts of the circuit where Kirchhoff's Current Law is applied to construct the flow graph.

As a final example let us calculate the voltage gain, v_o/v_i, of the common emitter amplifier stage of *Fig. 7* using the h-parameters for the transistor. A first step in constructing the flow graph from this circuit is to construct the flow graph giving the h-parameters. A flow graph constructed from this circuit is shown in *Fig. 7c*. It will be noted that neither v_o nor v_i is a source so the general gain rule can not be applied directly. Making use of the alternate rule just discussed we obtain:

$$\frac{v_o}{i_i} = \frac{-h_{fe}R_L + h_{ie}R_L/R_F}{\Delta} \quad (7a)$$

and

$$\frac{v_i}{i_i} = \frac{h_{ie}(1+h_{oe}R_L+R_L/R_F) - h_{fe}h_{re}R_L}{\Delta} \quad (7b)$$

Where Δ is the determinant from the general gain expression. The required voltage gain is obtained by dividing Equation 7a by Equation 7b to give:

$$\frac{v_o}{v_i} = \frac{h_{fe}R_L - h_{ie}R_L/R_F}{h_{fe}h_{re}R_L - h_{ie}(1+h_{oe}R_L+R_L/R_F)} \quad (7c)$$

Marketing and Production Trends in the Semiconductor Industry

H. E. MARROWS*

In this, the first installment of a series on marketing and production trends in the semiconductor industry, the author provides an overall view of the present status and what may be expected in the immediate future. Included in this discussion, as they relate to marketing and production trends, are transistor types, applications, standardization and components.

GROWTH OF THE semiconductor industry and its effect on associated industries in manufacturing equipment and components as well as those using transistors in their products has been so great that it requires a small staff to merely record and analyze what is taking place. In this series of articles we hope to bring you a picture of these developments, beginning with an overall summary.

About 30 companies are manufacturing transistors in this country, but a few of these manufacture transistors for their own or special uses. The Western Electric Company, for example, makes transistors mainly for the Bell Telephone System; other transistors it makes are for the exclusive use of the military agencies of the U. S. Government and their contractors. Some companies have just entered the commercial field, and others are considering entrance into the field.

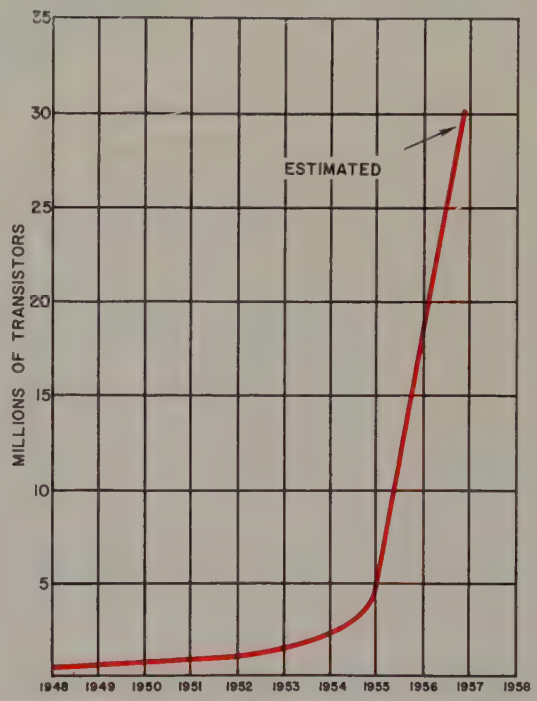


Fig. 1—Growth of transistor sales

Transistor Types

Transistors have been offered commercially since the early fifties and since then over 800 different code numbers have appeared. Of the 400-plus EIA types, it is significant that only about 5% were of the point contact types. This same ratio holds for the 400-plus non-EIA types. Incidentally, many of the EIA type numbers were originally coded by the manufacturer with his own special non-EIA codes, but we have not counted these transistors in both groups. The point contact types of transistors have dwindled down to a dozen or so and are used only in military applications and by the Bell Telephone System in communication equipment. It is felt that their continued use in these applications has probably been due to the vast amount of proven point contact circuitry available.

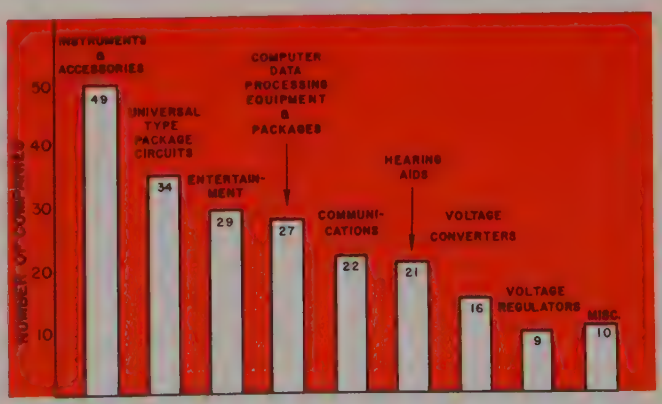
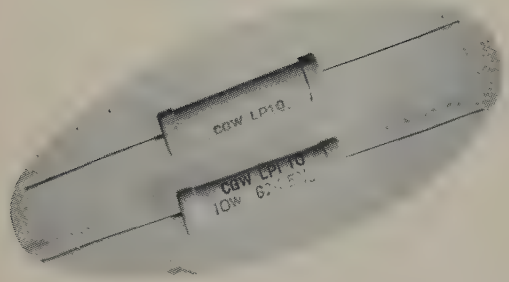


Fig. 2—Graph showing number of companies using transistors in commercial products by applications

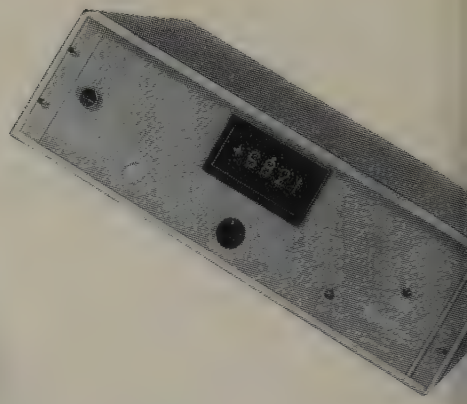
* *Author of "Transistor Engineering Reference Handbook"*



COMPONENTS

A ten-watt resistor made by Corning Glass Works.

A relay made in a standard transistor enclosure by Electronics Division, Elgin National Watch Company.



APPLICATIONS

"Transicon Datrac," made by Epsco, Incorporated, a fully transistorized analog-digital converter designed primarily for industrial usage.

All of the transistors being made commercially today are classed broadly as point contact, junction and surface barrier—all bipolar types. In the last year or so new processing innovations have overcome many limitations of earlier transistors. New transistors produced as a result are: Diffused Layer types, Tandem types and Micro-Alloy types. Special diodes which are sometimes compared to transistors are the so-called Unijunction type and the Shockley Semiconductor Laboratory Bistable Diode. Two other types of transistors, the Field-Effect and the Avalanche Junction, have appeared to be close to manufacture for some time, but as yet have not been announced. Adequate information on the "Spacistor" is not available for evaluation. The Field-Effect transistor, a unipolar type, would be of great interest because of the unusual circuit properties it affords. Activity in development work has been very intense. About 700 patents have been granted since early 1945 which are of interest to the transistor industry.

Transistor Applications

Figure 1 shows the growth of transistor sales over the years. Estimates for 1957 vary between 30 to 34 million units. On reading these figures, the first question that comes to mind is: where are all these transistors going? *Fig. 2* answers this question to some extent. Data for research and military applications is difficult to obtain and is not included here.

It is significant to note, if one studies the application trends, how the transistor makers and the product makers are putting an emphasis on the particular advantages that transistors have over vacuum tubes. In the early years, hearing aids led the market in the commercial use of transistors. In 1956, marketing reports showed portable radios used up some 5 million of the 13 million sold as against 1 million by the hearing aid industry. In 1956 a growing newcomer was the communications field, where some 1¼ million transistors were used. In 1957, the universal package or module-type circuit and the computer-data processing field have made tremendous inroads on the market. Just what this advance amounts to has not been precisely determined yet. Estimates as of now give the entertainment field 13 million; the package or module field (including computer-data processing) 4 million; military applications 4 million; communications 3 million; commercial development 2.5 million; hearing aids 1.5 million; instruments 1 million; and miscellaneous another million.

Projecting these trends, for 1958 the following estimate is made:

Entertainment	25	million transistors
Package (all types) ..	15	" "
Communications	10	" "
Military Applications .	10	" "
Misc. and Development	5	" "
Total	65	" "

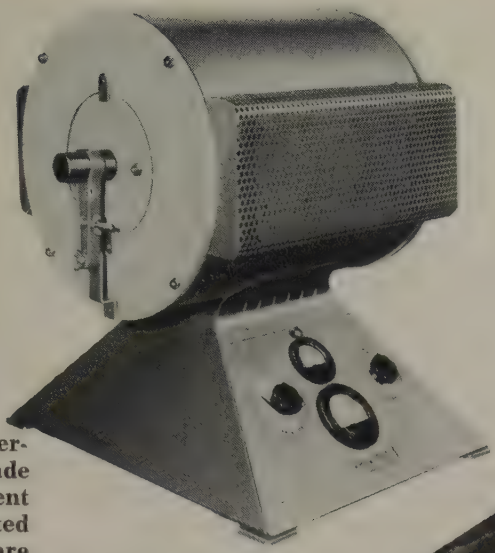
For 1958, while there will be intensive development work on TV receivers, no significant change to transistors is expected.

Transistor Standardization

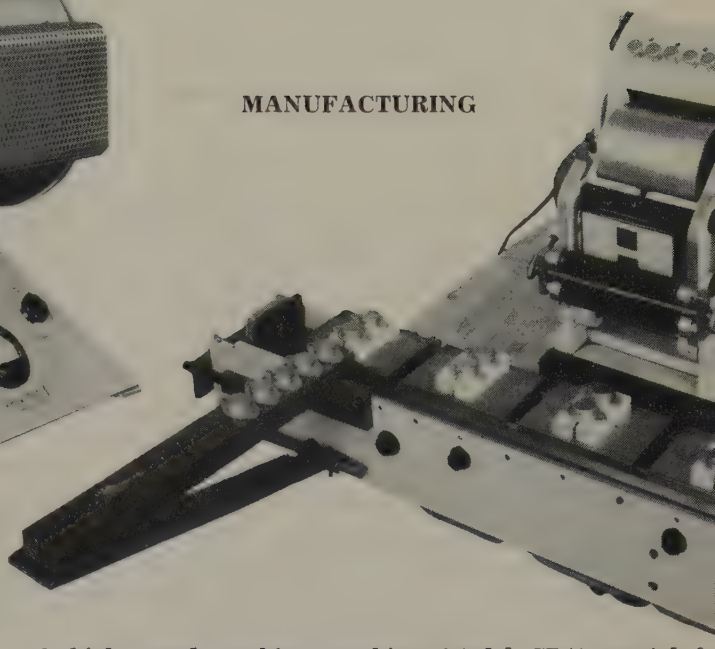
A great amount of unsung work has been done on transistor standardization and reliability. On the military side, MIL-T-19500 has been in use for general specifications on transistors. Task groups have been working diligently on JTC-14 specifications on transistors.

Recent reliability studies have shown that early Bell Telephone predictions on transistor life and capabilities were well founded. General Electric tested

A combination resolver-booster amplifier made by Reeves Instrument Corporation. Mounted behind the resolver are two transistorized amplifiers which provide a high input impedance and a feedback loop for the compensating winding.



A High Temperature Tube Furnace made by Hevi-Duty Electric Company for transistor manufacturing companies.



A high speed marking machine, Model CP/1 special fo power transistors, developed by Popper & Sons, Inc.

some 2,000 transistors, selected at random from ten lots. After 1,000 hours only 0.25% could not be operated at peak readings. Extensive and exhaustive electrical tests made by a number of groups over periods of 10,000 to 20,000 hours showed slight variations in characteristics and few failures. In the General Electric tests mentioned above, the transistors were subjected to shock test at 8,000 g (16 times greater than the most stringent military specifications for transistors) and 60-75% could operate at full power. Clevite Transistor Products, reporting a typical test of 12 power transistors made to military specifications showed, among other favorable results, that after a test period of more than 12 hundred hours the average power gain degradation was a 1 *db* drop.

The Bell Telephone Laboratories in several reports revealed interesting data on the Western Electric P1 Carrier System, an all-transistor carrier telephone system designed for rural telephone lines. The studies involved about 400 transistors with a total transistor-hours reaching approximately 4.3 million. Over this period actual failures amounted to 34 transistors. All of these failures occurred with early laboratory development types.

Transistor Components

Along with transistors is the development and growth of a huge components business which is directed to transistorized circuits and applications. Several hundred different types of transformers are being manufactured for transistor circuitry. Almost every type of component manufacturer has had to design new products to accommodate the growing use of transistors. Even hardware must be smaller and several companies are promoting their micro-screw products in this direction.

A quick look at the statistics on the companies who are fighting for the transistor components' business shows the following:

Component	No. of Mfrs.
Transformers	20
Capacitors	19
Potentiometers	9
Batteries	8
Motors	4
Speakers	3
Microphones	3
Receivers (headphones)	3
Misc. (crystals, thermistors, relays, etc.)	23
Hardware	32

Manufacturing equipment companies are finding new uses for their products. Bausch and Lomb Optical Company sells special microscopes, Felker Manufacturing Company sells dicing equipment, Weldmatic Division of Unitek Corporation sells welding equipment, Popper & Sons, Inc. sells marking machines and Brinkman Instruments sells micro manipulators to the manufacturers of transistors. Electrical Industries, The Hermaseal Co., Inc. and Hermetic Seal Products Co. manufacture bases and closures for transistors.

The Immediate Future

In an overall summary, a number of questions come to mind. What will competition from foreign countries do to us? At present, the threat is not great, but some

indications which have appeared seem to be in the entertainment field. For example, in the early part of 1957 one Japanese company produced almost a quarter million entertainment type transistors in one month.

Another question: What are the present developments being worked on which will become important transistor products in the coming year or the next few years? Most authorities appear to agree that industrial-communications-military applications will pass the entertainment field in the number of transistors used by 1958.

However, the entertainment field will itself use many more transistors. The new, or at least more intensely marketed, entertainment uses will be table model radios, phonographs, tape recorders, remote amplifiers and pre-amplifiers. Some FM tuners, all-wave and short wave receivers will start to appear. Kits of broadcast receivers are becoming more and more intensely marketed with fairly impressive sales being made with one and two transistor toy kits. Transistorized auto radios will prevail in the 1958 market, but 1959 model cars will start to turn heavily to all-transistor radios.

In the industrial market many new applications are appearing and have made impressive gains with engineers who previously avoided electronic devices. These new applications are measuring equipment, electrical test sets, photographic and direct-writing recording instruments, tool controls, voltage regulation, servo systems, sensing devices, and a host of data processing and computer equipments. Fire and burglar alarm systems are particularly susceptible to transistor use and will be very appealing to plant protection people.

The last developments mentioned above have also attracted builders of homes and other developments related to the household are being seriously considered. Controls for windows, doors, lights and appliances are being worked on and should start reaching the market in late 1958 or early 1959. Motels and hotels are bound to be interested in these new developments.

A number of interesting developments are shaping up for the automobile industry. Fuel injection systems, ignition systems, voltage regulators and transmission controls are among the leading, in addition to the auto radios mentioned previously. One manufacturer is working on a computer which will automatically calculate average miles per gallon, average miles per trip, average speed, etc.

Continuing in the transportation field: aviation, boating and trucking applications are being eyed by the industry. In aviation, fuel gages, power generators, beacon transmitters, emergency transmitters and various controls are being worked on. Direction finders, receivers and various controls are slated for the pleasure boats.

Probably the biggest advances will be made in the communications field in the next year or so. The Western Electric P-Carrier as well as the new Line Concentrators (where almost 200 transistors are to be used with over 100 diodes) developed by the Bell Telephone Laboratories, mark a significant advance in telephone work. Electronic switching will not be ready yet for large scale applications but uses will appear this year for local or small scale projects such as private switchboards. Already introduced in communications are power rectifiers, voltage regulators, personal paging, selective mobile telephone calling and high speed data transmission, power-line carriers, public address and intercom applications. Work continues on *i-f* and video amplifiers, high speed PCM trunk carrier and submarine cable developments.

On the military side, transistor developments are touching every aspect of warfare. Guidance systems for missiles, communications, radar, servo systems, fuses, power supplies, instrumentation controls, computer and data processing are among the main applications we hope to touch upon in subsequent articles.

CHARACTERISTICS CHART of NEW TRANSISTORS

SEMICONDUCTOR PRODUCTS believes that a tabulation of the new transistors released every four months will be of special interest to its readers. The first of these tabulations, for the period July 1 to October 31, 1957, is presented here—in type number order and indicating the major characteristics along with the manufacturers of each type. The characteristic symbols are those recommended by the I.R.E.

In the comparatively few years since their inception, transistors have indeed made rapid strides, and it will be noted that in this tabulation, alone, 224 new transistors are included. The characteristics of JETEC registered types are those supplied by the manufacturer of this registered type. This listing is intended merely as a guide; complete specifications, prices, and availability should be obtained direct from the manufacturers.

MANUFACTURERS

(In Order of Code Letters)

AMP— Amperex Electronic Corp.
BEN— Bendix Aviation Corp.
BOG— Bogue Electric Mfg. Co.
BTHB—British Thomson-Houston Export Co., Ltd.
CBS— CBS-Hytron
CLE— Clevite Transistor Products, Inc.
DEL— Delco Radio Div., General Motors Corp.
EEVB—English Electric Valve Co., Ltd.
ESEB— Edison Swan Electric Co., Ltd.
FTHF—French Thomson-Houston Semiconductor Dept.
GECB—General Electric Co., Ltd.
GE— General Electric Co., Electronics Div. Semiconductor Prod.
GTC— General Transistor Corp.
HUG— Hughes Aircraft Co.
HIVB— Hivac Ltd.
IND— Industro Transistor Corp.
LCTF— Laboratoire Central de Telecommunications
MIN— Minneapolis-Honeywell Regulator Co.
MOT— Motorola, Inc.
MUL— Mullard Ltd.
NPC— Nucleonics Products Co.
PHI— Philco Corp., Lansdale Tube Co.
PYEB—Pye Industrial Electronics, Ltd.
RAY— Raytheon Mfg. Co.
RCA— Radio Corp. of America, Semiconductor Div.
SIE— Siemens & Halske Aktiengesellschaft
SPR— Sprague Electric Co.
SYL— Sylvania Electric Products Inc.
STCB— Standard Telephone & Cables, Ltd.
TKDE—Suddeutsche Telefon-Apparate-, Kabel und Drahtwerke
TRA— Transitron Electronic Corp.
TFKG—Telefunken Ltd.
TII— Texas Instruments
TUN— Tung-Sol Electric, Inc.
TOK— Tokyo Tsushin Kogyo, Ltd.
WEC— Western Electric Co., Inc.,
WEST—Westinghouse Electric Corp.

CHARACTERISTICS CHART of NEW TRANSISTORS

TYPE NO.	USE (See Code Below)	TYPE (See Code Below)	MAT	Max. Ratings @ 25° C				Typical Characteristics			MFR. (See code at end of chart)
				P_c (mw)	DERATING °C/W	V_{CB}	V_{CE}	$f_{\alpha\beta}$ (mc)	Gain PARAMETER and (condition)	Gain VALUE	
2N59	2	PNP(A)	GE	180	350	25	20	1.80	h_{fe}(I_c-100 ma)	90	WEST
2N60	2	PNP(A)	GE	180	350	25	20	1.50	h_{fe}(I_c-100 ma)	70	WEST
2N61	2	PNP(A)	GE	180	350	25	20	1.10	h_{fe}(I_c-100 ma)	50	WEST
2N130A	2	PNP(A)	GE	100	600	—	40	.70	h_{fe}(I_e-1 ma)	22	RAY
2N131A	2	PNP(A)	GE	100	600	—	30	.80	h_{fe}(I_e-1 ma)	45	RAY
2N132A	2	PNP(A)	GE	100	600	—	20	1.00	h_{fe}(I_e-1 ma)	90	RAY
2N133A	2	PNP(A)	GE	100	600	—	20	.80	h_{fe}(I_e-1 ma)	50	RAY
2N155	3	PNP(A)	GE	—	3.0	30	—	.15	h_{FE}(I_c-1A)	32	CBS-NPC
2N158	3	PNP(A)	GE	8500	3	−60	—	0.18	h_{FE}(I_c-.25A)	41	CBS
2N158A	3	PNP(A)	GE	8500	3	−80	−60	0.18	h_{FE}(I_c-.25A)	41	CBS
2N176	3	PNP(A)	GE	—	1.0	—	30	—	h_{FE}(I_c-.5A)	50	MOT-NPC
2N213	1	NPN(A)	GE	50	—	—	25	—	h_{fe}(I_e-1 ma)	150	SYL
2N229	—	NPN	GE	50	—	10	12	1.60	h_{fe}(I_e-1 ma)	24	SYL
2N233A	4	NPN(A)	GE	50	1000	10	10	—	h_{fe}(I_e-1 ma)	5	SYL
2N234	3	PNP	GE	—	2.0	—	30	—	h_{FE}(I_c-.5 A)	25	BEN
2N234A[6]	—	—	—	—	—	—	—	—	——	—	BEN
2N236	3	PNP	GE	—	2.0	—	40	—	h_{FE}(I_e-.75 A)	35	BEN
2N236A[6]	—	—	—	—	—	—	—	—	——	—	BEN
2N242	3	PNP(A)	GE	15W	—	—	45	0.4	h_{FE}(I_c-500 ma)	50	TUN
2N274	4	PNP(D)	GE	80	—	35	—	30	h_{fe}(I_e-1 ma)	60	RCA
2N285	3	PNP	GE	—	2.0	—	40	—	h_{FE}(I_c-.5 A)	125	BEN
2N285A[6]	—	—	—	—	—	—	—	—	——	—	BEN
2N296	3	PNP(A)	GE	20W	—	—	60	—	h_{FE}	19	SYL
2N306	1	NPN(A)	GE	50	1000	20	—	.75	h_{fe}(I_e-1 ma)	30	SYL
2N307A	3	PNP	GE	16W*	3	35	—	f_{ac}-7kc	PG(I_e-.5A)	27	SYL
2N325	3	PNP(A)	GE	12W	—	35	—	.15	h_{FE}(I_c-.5 A)	45	SYL
2N326	3	NPN(A)	GE	7000	—	35	—	.15	h_{FE}(I_c-.5 A)	45	SYL
2N332	2, 5	NPN(D)	SI	200	—	45	45	7	h_{fe}(I_e-1 ma)	14	TRA
2N333	2, 5	NPN(D)	SI	200	—	45	45	9	h_{fe}(I_e-1 ma)	28	TRA
2N334	2, 5	NPN(D)	SI	200	—	45	45	11	h_{fe}(I_e-1 ma)	45	TRA
2N335	2, 5	NPN(D)	SI	200	—	45	45	10	h_{fe}(I_e-1 ma)	60	TRA
2N336	2, 5	NPN(D)	SI	200	—	45	45	13	h_{fe}(I_e-1 ma)	100	TRA
2N359	2	PNP(A)	GE	160	360	—	30	1.20	PG[14] (.25 W)	30 db	RAY
2N360	2	PNP(A)	GE	160	360	—	30	1.20	PG[14] (.25 W)	27 db	RAY
2N361	2	PNP(A)	GE	160	360	—	40	1.00	PG[14] (.25W)	24 db	RAY
2N362	2	PNP(A)	GE	160	360	—	20	1.20	PG[14] (1mw)	40 db	RAY
2N363	2	PNP(A)	GE	160	360	—	40	1.00	PG[14] (1 mw)	35 db	RAY
2N370	4	PNP(D)	GE	80	—	20	—	30	h_{fe}(I_e-20 ma)	60	RCA
2N371	4	PNP(D)	GE	80	—	20	—	30	h_{fe}(I_e-20 ma)	60	RCA
2N372	4	PNP(D)	GE	80	—	20	—	30	h_{fe}(I_e-1 ma)	60	RCA
2N377	5	NPN(A)	GE	150	500	25	20	5.00	h_{fe}(I_e-1 ma)	40	SYL
2N378	3	PNP(A)	GE	15W	—	40	—	0.3	h_{FE}(I_c-500 ma)	35	TUN
2N379	3	PNP(A)	GE	15W	—	80	—	0.3	h_{FE}(I_c-500 ma)	30	TUN
2N380	3	PNP(A)	GE	15W	—	60	—	0.4	h_{FE}(I_c-500 ma)	60	TUN
2N381	2	PNP(A)	GE	200	—	25	—	1.2	h_{fe}(I_c-1 ma)	50	TUN

NOTATIONS

Under Use

1—Low power α-f equal to or less than 50 *mw*
2—Medium power α-f > 50 *mw* and equal to or less than 500 *mw*
3—Power > 500 *mw*
4—α-f/i-f
5—Switching & Computer

Under Type

A—Alloyed
D—Diffused or Drift
G—Grown
M—Microalloy
O—Other
S—Surface Barrier
UNI—Unijunction Transistor

Under f αb

* Maximum Frequency
\# Figure of Merit

Other

6—without cap
7—2N405 with flexible leads
8—2N407 with flexible leads
9—2N409 with flexible leads
10—2N411 with flexible leads
11—2N420 with terminal cap
12—Tetrode
13—In Either Direction
14—Class B
15—Rise time 0.5 μsec max; storage plus Fall time 0.6 μsec max.

CHARACTERISTICS CHART of NEW TRANSISTORS

TYPE NO.	USE (See Code Below)	TYPE (See Code Below)	MAT	Max. Ratings @ 25° C				Typical Characteristics			MFR. (See code at end of chart)
				P_c (mw)	DERATING °C/W	V_{CB}	V_{CE}	$f_{\alpha\beta}$ (mc)	Gain PARAMETER and (condition)	Gain VALUE	
2N382	2	PNP(A)	GE	200	—	25	—	1.5	h_{fe}(I_c-1 ma)	75	TUN
2N383	2	PNP(A)	GE	200	—	25	—	1.8	h_{fe}(I_c-1 ma)	100	TUN
2N384	4	PNP(D)	GE	120	—	30	—	100	h_{fe}(I_c-1.5 ma)	60	RCA
2N385	5	NPN(A)	GE	150	500	25	25	6.00	h_{fe}(I_c-10 ma)	60	SYL
2N388	5	NPN(A)	GE	150	500	25	20	8.00	h_{fe}(I_c-1 ma)	80	SYL
2N389	3	NPN	SI	37500	—	60	—	3	h_{fe}(I_c-.3 A)	10	TII
2N396	4, 5	PNP	GE	150	—	—	20	5.00	—	—	GE
2N397	4, 5	PNP	GE	150	—	—	10	8.00	—	—	GE
2N398	5	PNP(A)	GE	50	—	105	105	—	h_{fe}(I_c-5 ma)	60	RCA
2N399	3	PNP	GE	—	2.0	—	40	—	h_{FE}(I_c-.75 A)	40	BEN
2N400	3	PNP	GE	—	2.0	—	40	—	h_{FE} (I_c-1.3 A)	80	BEN
2N401	3	PNP	GE	—	2.0	—	40	—	h_{FE}(I_c-.5 A)	40	BEN
2N402	2	PNP(A)	GE	180	350	25	20	.60	h_{FE}(I_c-1 A)	40	WEST
2N403	2	PNP(A)	GE	180	350	25	20	1.00	h_{FE}(I_c-5 A)	60	WEST
2N404	5	PNP(A)	GE	120	—	25	24	12	—	—	RCA-TUN
2N405	2	PNP(A)	GE	150	—	20	18	—	h_{fe}(I_e-1 ma)	35	RCA
2N406[7]	—	—	—	—	—	—	—	—	—	—	RCA
2N407	2	PNP(A)	GE	150	—	20	18	—	h_{fe}(I_e-50 ma)	65	RCA
2N408[8]	—	—	—	—	—	—	—	—	—	—	RCA
2N409	4	PNP(A)	GE	80	—	13	—	14#	h_{fe}(I_e-1 ma)	48	RCA
2N410[9]	—	—	—	—	—	—	—	—	—	—	RCA
2N411	4	PNP(A)	GE	80	—	13	—	16.5#	h_{fe}(I_e-.6 ma)	75	RCA
2N412[10]	—	—	—	—	—	—	—	—	—	—	RCA
2N413	4	PNP(A)	GE	150	400	—	18	3.00	h_{fe}(I_e-1 ma)	30	RAY-IND-TUN
2N413A	4	PNP	GE	150	400	—	18	—	PG (455 kc)	32	IND-TUN
2N414	4	PNP(A)	GE	150	400	—	15	5.00	h_{fe}(I_e-1 ma)	60	RAY-IND-TUN
2N414A	4	PNP	GE	150	400	—	15	—	PG (455 kc)	35	IND-TUN
2N416	4	PNP(A)	GE	150	400	—	12	10	h_{fe}(I_e-1 ma)	80	RAY-IND-TUN
2N417	4	PNP(A)	GE	150	400	—	10	20	h_{fe}(I_e-1 ma)	140	RAY-IND-TUN
2N418	3	PNP	GE	—	1.5	40	—	—	PG	34	BEN
2N419	3	PNP	GE	—	1.5	50	—	—	—	—	BEN
2N420	3, 5	PNP	GE	—	2.0	—	40	—	h_{FE}(I_c-4 A)	45	BEN
2N421[11]	—	—	—	—	—	—	—	—	—	—	BEN
2N422	1	PNP(A)	GE	160	400	—	20	.80	h_{fe}(I_c-.5 ma)	50	RAY
2N424	3	NPN(D)	GE	37.5	—	—	60	—	h_{FE}(I_c-.3 ma)	30	TII
2N425	5	PNP(A)	GE	150	400	—	20	4.00	h_{fe}(I_c-30 ma)	30	RAY-IND-TUN
2N426	5	PNP(A)	GE	150	400	—	18	6.00	h_{fe}(I_c-40 ma)	40	RAY-IND-TUN
2N427	5	PNP(A)	GE	150	400	—	15	11	h_{fe}(I_c-55 ma)	55	RAY-IND-TUN
2N428	5	PNP(A)	GE	150	400	—	12	17	h_{fe}(I_c-80 ma)	80	RAY-IND-TUN
2N431	4, 5	NPN	SI	150	—	—	15	23	h_{fe}	15	GE
2N432	4, 5	NPN	SI	150	—	—	15	25	h_{fe}	35	GE
2N433	4, 5	NPN	SI	150	—	—	15	28	h_{fe}	60	GE
2N434	4, 5	NPN	SI	150	—	—	15	30	h_{fe}	110	GE
2N438	4, 5	NPN(A)	GE	100	—	30	25	3.75	h_{fe}(I_e-1 ma)	25	CBS
2N439	4, 5	NPN(A)	GE	100	—	30	20	7.50	h_{fe}(I_e-1 ma)	35	CBS

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3—Power > 500 mw
4—r-f/i-f
5—Switching & Computer

Under Type

A—Alloyed
D—Diffused or Drift
G—Grown
M—Microalloy
O—Other
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Under f ab

* Maximum Frequency
# Figure of Merit

Other

6—without cap
7—2N405 with flexible leads
8—2N407 with flexible leads
9—2N409 with flexible leads
10—2N411 with flexible leads
11—2N420 with terminal cap
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15—Rise time 0.5 μsec max; storage plus Fall time 0.6 μsec max.

CHARACTERISTICS CHART of NEW TRANSISTORS

TYPE NO.	USE (See Code Below)	TYPE (See Code Below)	MAT	Max. Ratings @ 25° C				Typical Characteristics			MFR. (See code at end of chart)
				P_c (mw)	DERATING °C/W	V_{CB}	V_{CE}	$f_{\alpha\beta}$ (mc)	Gain PARAMETER and (condition)	Gain VALUE	
2N440	4, 5	NPN(A)	GE	100	—	30	15	15	h_{fe}(I_c-1 ma)	65	CBS
2N441	3	PNP	GE	—	1.2	40	—	—	h_{FE}(I_c-5 A)	33	DEL
2N442	3	PNP	GE	—	1.2	50	—	—	h_{FE}(I_c-5 A)	33	DEL
2N443	3	PNP	GE	—	1.2	60	—	—	h_{FE}(I_c-5 A)	33	DEL
2N444	2, 5	NPN(A)	GE	100	500	15	15	.50	h_{fe}(I_e-1 ma)	15	GTC
2N445	2, 5	NPN(A)	GE	100	500	15	12	2.00	h_{fe}(I_e-1 ma)	35	GTC
2N446	2, 5	NPN(A)	GE	100	500	15	10	5.00	h_{fe}(I_e-1 ma)	60	GTC
2N447	2, 5	NPN(A)	GE	100	500	15	6	9.00	h_{fe}(I_e-1 ma)	125	GTC
2N451	3	NPN(D)	SI	—	1.5	65	—	—	h_{FE}(I_c-1 A)	10	GE
2N456	3	PNP(A)	GE	3500	—	40	—	—	h_{fe}(I_c-1 A)	45	TII
2N457	3	PNP(A)	GE	3500	—	60	—	—	h_{fe}(I_c-1 A)	45	TII
2N459	3	PNP(A)	GE	15W	—	105	—	0.3	h_{FE}(I_c-500 ma)	40	TUN
2N460	2	PNP(A)	GE	200	—	45	—	1.20	h_{fe}(I_e-1 ma)	24	TUN
2N461	2	PNP(A)	GE	200	—	45	—	1.20	h_{fe}(I_e-1 ma)	49	TUN
2N462	2, 5	PNP(A)	GE	150	—	40	—	.50	h_{FE}(.5V.-200 ma)	45[13]	PHI
2N464	2	PNP(A)	GE	160	400	—	40	.70	h_{fe}(I_e-1 ma)	22	RAY
2N465	2	PNP(A)	GE	160	400	—	30	.80	h_{fe}(I_e-1 ma)	45	RAY
2N466	2	PNP(A)	GE	160	400	—	20	1.00	h_{fe}(I_e-1 ma)	90	RAY
2N467	2	PNP(A)	GE	160	400	—	15	1.20	h_{fe}(I_e-1 ma)	180	RAY
2N470	2, 5	NPN(D)	SI	200	1000	15	15	8.00	h_{fe}(I_e-1 ma)	16	TRA
2N471	2, 5	NPN	SI	200	1000	30	30	8.00	h_{fe}(I_e-1 ma)	16	TRA
2N472	2, 5	NPN	SI	200	1000	45	45	8.00	h_{fe}(I_e-1 ma)	16	TRA
2N473	2, 5	NPN(D)	SI	200	1000	15	15	10	h_{fe}(I_e-1 ma)	30	TRA
2N474	2, 5	NPN	SI	200	1000	30	30	10	h_{fe}(I_e-1 ma)	30	TRA
2N475	2, 5	NPN	SI	200	1000	45	45	10	h_{fe}(I_e-1 ma)	30	TRA
2N476	2, 4	NPN	SI	200	1000	15	15	17	h_{fe}(I_e-1 ma)	45	TRA
2N477	2, 4	NPN	SI	200	1000	30	30	17	h_{fe}(I_e-1 ma)	45	TRA
2N478	2, 5	NPN(D)	SI	200	1000	15	15	11	h_{fe}(I_e-1 ma)	60	TRA
2N479	2, 5	NPN	SI	200	1000	30	30	11	h_{fe}(I_e-1 ma)	60	TRA
2N480	2, 5	NPN	SI	200	1000	45	45	11	h_{fe}(I_e-1 ma)	60	TRA
2N481	4	PNP(A)	GE	50	—	—	12	4.00	——	—	RAY-TUN
2N482	4	PNP(A)	GE	50	—	—	12	3.00	PG (455 kc)	31	RAY-TUN
2N483	4	PNP(A)	GE	50	—	—	12	5.00	PG (455 kc)	35	RAY-TUN
2N484	4	PNP(A)	GE	50	—	—	10	9.00	PG (455 kc)	39	RAY-TUN
2N485	4	PNP(A)	GE	50	—	—	12	5.00	Conv. G (1 mc)	26	RAY-TUN
2N486	4	PNP(A)	GE	50	—	—	10	9.00	Conv. G (1 mc)	30	RAY-TUN
2N489	5	(UNI)	SI	250	—	—	—	.90	——	—	GE
2N490	5	(UNI)	SI	250	—	—	—	.70	——	—	GE
2N491	5	(UNI)	SI	250	—	—	—	.80	——	—	GE
2N492	5	(UNI)	SI	250	—	—	—	.70	——	—	GE
2N493	5	(UNI)	SI	250	—	—	—	.70	——	—	GE
2N494	5	(UNI)	SI	250	—	—	—	.65	——	—	GE
2N495	4	PNP(A)	SI	150	770	25	25	15*	h_{fe}(6V-1 ma)	18	PHI
2N496	5	PNP(A)	SI	150	770	10	10	25*	h_{fe}(6V-1 ma)	18	PHI

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Under Type

A—Alloyed
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Under f αb

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2N497	3	NPN(D)	SI	4000	—	60	60	—	h_{fe}	20	TII
2N498	3	NPN(D)	SI	4000	—	100	100	—	h_{fe}	20	TII
2N499	4	PNP(D)	GE	75	800	30	18	320*	PG (100 mc)	10	PHI
2N500	4	PNP(D)	GE	75	800	20	15	—	PO (200 mc)	20 mw	PHI
2N501	5	PNP(D)	GE	50	—	15	—	—	h_{FE}(OV.-10 ma)	50	PHI
2N502	4	PNP(D)	GE	60	1000	20	15	500*	PG(200 mc)	8	PHI
2N503	4	PNP(D)	GE	60	1000	20	15	—	PG(100 mc)	11	PHI
2N504	4	PNP(D)	GE	50	—	35	25	50*	h_{fe}(12V-1 ma)	16	PHI
2N508	—	PNP	—	—	—	—	—	—	——	—	GE
2N515	4	NPN	GE	50	1000	—	18	3	PG(if cir.)	25	SYL
2N516	4	NPN	GE	50	1000	—	18	3	PG(if cir.)	27	SYL
2N517	4	NPN	GE	50	1000	—	18	3	PG(if cir.)	29	SYL
2N529	—	—	GE	100	500	15	—	2.50	h_{fe}(I_e-1 ma)	18	GTC
2N530	—	—	GE	100	500	15	—	3.00	h_{fe}(I_e-1 ma)	23	GTC
2N531	—	—	GE	100	500	15	—	3.50	h_{fe}(I_e-1 ma)	28	GTC
2N532	—	—	GE	100	500	15	—	4.00	h_{fe}(I_e-1 ma)	33	GTC
2N533	—	—	GE	100	500	15	—	4.50	h_{fe}(I_e-1 ma)	38	GTC
2N534	1	PNP(A)	GE	50	800	—	50	2.00	h_{fe}(5V-1 ma)	100	PHI
2N535	1	PNP(A)	GE	50	800	—	20	2.00	h_{fe}(5V-1 ma)	100	PHI
2N536	5	PNP(A)	GE	50	800	—	20	2.00	——	—	PHI
2N541	2, 5	NPN(D)	SI	200	—	15	15	15	h_{fe}(I_e-1 ma)	120	TRA
2N542	2, 5	NPN(D)	SI	200	—	30	30	15	h_{fe}(I_e-1 ma)	120	TRA
2N543	2, 5	NPN(D)	SI	200	—	45	45	15	h_{fe}(I_e-1 ma)	120	TRA
2N545[15]	3, 5	NPN(D)	SI	5W	—	60	60	4	h_{FE}(I_c-.5 A)	30	TRA
2N546[15]	3, 5	NPN(D)	SI	5W	—	30	30	4	h_{FE}(I_c-.5 A)	30	TRA
2N547	3, 5	NPN(D)	SI	5W	—	60	60	4	h_{FE}(I_c-5 A)	35	TRA
2N548	3, 5	NPN(D)	SI	5W	—	30	30	4	h_{FE}(I_c-5A)	35	TRA
2N549	3, 5	NPN(D)	SI	5W	—	60	60	4	h_{FE}(I_c-2A)	35	TRA
2N550	3, 5	NPN(D)	SI	5W	—	30	30	4	h_{FE}(I_c-2 A)	35	TRA
2N551	3, 5	NPN(D)	SI	5W	—	60	60	4	h_{FE}(I_c-50 ma)	30	TRA
2N552	3, 5	NPN(D)	SI	5W	—	30	30	4	h_{FE}(I_c-50 ma)	30	TRA
2T71	4	NPN(G)	GE	50	800	25	—	20	h_{fe}(I_e-1 ma)	49	TOK
2T72	4	NPN(G)	GE	50	800	25	—	20	h_{fe}(I_e-1 ma)	32	TOK
2T85	2	NPN(A)	GE	200	250	25	—	1.00	h_{fe}(I_e-1 ma)	45	TOK
CK754	2	PNP	GE	100	600	—	10	1.20	h_{fe}(I_e-20 ma)	300	RAY
CTP1112	3	PNP	GE	30W	—	80	—	—	——	—	CLE
CTP1117	3	PNP	GE	30W	—	40	—	—	——	—	CLE
DT100	3	PNP	GE	—	1.0	100	—	—	h_{FE}(I_c-5 A)	39	DEL
GT210H	—	PNP(A)	GE	90	—	12	—	—	——	120	GTC
GT792R	4	NPN(A)	GE	90	550	—	10	6.00	PG(455 kc)	30	GTC
GT905R	4	NPN(A)	GE	90	550	—	18	—	h_{fe}(I_e-1 ma)	40	GTC
GT948R	4	NPN(A)	GE	90	550	—	10	3.50	PG(455 kc)	30	GTC
GT949R	4	NPN(A)	GE	90	550	—	12	—	h_{fe}(I_e-1 ma)	120	GTC
H200E[12]	3	PNP(A)	GE	—	1.0	60		—	h_{FE}(I_c-5 A)	40	MIN
HA5016	2	NPN(A)	GE	400	—	40		1.00	h_{fe}(I_e-5 ma)	25	HUG

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HA5021	2	NPN(A)	GE	300	150	20	—	5.00	$h_{fe}(I_e$-1 ma)	49	HUG
HA7501	2, 5	PNP(A)	SI	500	250	60	—	.50	$h_{fe}(I_e$-1 ma)	4	HUG
HA7502	2, 5	PNP	SI	500	250	60	—	.90	$h_{fe}(I_e$-1 ma)	16	HUG
MN19	5	—	—	—	—	40	20	8.00	h_{FE}	40	MOT
OC16	3, 5	PNP(A)	GE	—	1.2	32	—	.20	$h_{fe}(I_c$-2 A)	22	MUL
OC73	2, 5	PNP(A)	GE	35	400	30	—	.50	$h_{fe}(I_c$-.5 ma)	45	MUL
OC76	5	PNP(A)	GE	125	400	32	—	.35	$h_{fe}(I_c$-10 ma)	45	MUL
OC77	5	PNP(A)	GE	125	400	60	—	.35	$h_{fe}(I_c$-10 ma)	45	MUL
PC-6	5	PC	GE	200	—	80	—	5.00	$h_{fb}(I_e$-.2 ma)	(a)5	SPR
SX361	3, 5	PNP(A)	GE	20W	—	66	60	200kc	$h_{FE}(I_c$-.5 A)	70	TRA
SX362	3, 5	PNP(A)	GE	20W	—	66	60	200kc	$h_{FE}(I_c$-1 A)	30	TRA
SX363	3, 5	PNP(A)	GE	20 W	—	66	60	200kc	$h_{FE}(I_c$-2 A)	30	TRA
SX364	3, 5	PNP(A)	GE	20W	—	66	60	200kc	$h_{FE}(I_c$-2 A)	50	TRA
TF77/30	—	PNP(A)	GE	—	13	32	—	—	$h_{fe}(I_c$-1 ma)	25	SIE
TF80/30	—	PNP(A)	GE	—	4.0	—	32	—	$h_{FE}(I_c$-50 ma)	25	SIE
TRO3	5	NPN(A)	GE	100	—	20	—	—	$h_{fe}(I_e$-1 ma)	53	IND
TRO4	5	NPN(A)	GE	100	—	20	—	4.00	$h_{fe}(I_e$-1 ma)	30	IND
TRO5	5	NPN(A)	GE	100	—	20	—	—	$h_{fe}(I_e$-1 ma)	30	IND
TRO7	5	NPN(A)	GE	100	—	15	—	—	$h_{fe}(I_e$-1 ma)	40	IND
TRO8	5	NPNA	GE	100	—	20	—	4.00	$h_{fe}(I_e$-1 ma)	30	IND
TRO9	5	NPN(A)	GE	100	—	30	—	.70	$h_{fe}(I_e$-1 ma)	30	IND
TR10	—	PNP(A)	GE	150	—	50	—	—	$h_{fe}(I_e$-1 ma)	18	IND
TR11	—	PNP(A)	GE	125	—	100	—	—	$h_{fe}(I_e$-1 ma)	18	IND
TR12	5	PNP	GE	70	—	25	—	—	$h_{fe}(I_e$-1 ma)	15	IND
TR13	2	PNP	GE	70	—	25	—	—	$h_{fe}(I_e$-1 ma)	28	IND
TR14	2	PNP	GE	70	—	25	—	—	$h_{fe}(I_e$-1 ma)	45	IND
TR15	2	PNP(A)	GE	125	—	25	—	—	$h_{fe}(I_e$-1 ma)	75	IND
TR16	2	PNP(A)	GE	125	—	25	—	—	$h_{fe}(I_e$-1 ma)	150	IND
TR17	2	PNP(A)	GE	125	—	25	—	—	$h_{fe}(I_e$-1 ma)	150	IND
TR18	5	PNP	GE	70	—	25	—	.70	$h_{fe}(I_e$-1 ma)	45	IND
TR19	5	PNP(A)	GE	125	—	25	—	2.00	$h_{fe}(I_e$-1 ma)	100	IND
TR20	5	PNP(A)	GE	100	—	30	—	—	$h_{fe}(I_e$-1 ma)	20	IND
TR21	2	PNP(A)	GE	125	—	12	—	—	$h_{fe}(I_e$-1 ma)	20	IND
TR34	2	PNP	GE	50	1000	40	—	.60	$h_{fe}(I_e$-1 ma)	40	IND
TR35	2	PNP	GE	50	1000	40	—	.80	$h_{fe}(I_e$-1 ma)	40	IND
TR43	—	PNP	GE	150	500	45	—	1.00	$h_{fe}(I_e$-1 ma)	50	IND
TR43A	—	PNP	GE	150	500	45	—	1.00	$h_{fe}(I_e$-1 ma)	43	IND
TR44	—	PNP	GE	150	500	45	—	1.00	$h_{fe}(I_e$-1 ma)	22	IND
TR45	—	PNP	GE	150	500	45	—	1.00	$h_{fe}(I_e$-1 ma)	12	IND
TR63	—	PNP	GE	100	600	—	22	.60	$h_{fe}(I_e$-1 ma)	22	IND
TR64	—	PNP	GE	100	600	15	—	.80	$h_{fe}(I_e$-1 ma)	45	IND
TR65	—	PNP	GE	100	600	12	—	1.20	$h_{fe}(I_e$-1 ma)	90	IND
TR77	—	PNP(A)	GE	35	-	25	—	.70	$h_{fe}(I_c$-.7ma)	55	IND
TR81	2	PNP	GE	70	—	25	—	—	$h_{fe}(I_e$-1 ma)	65	IND
TR87	5	PNP	GE	70	500	25	—	1.00	$h_{fe}(I_e$-1 ma)	28	IND

NOTATIONS

Under Use

1—Low power a-f equal to or less than 50 *mw*
2—Medium power a-f > 50 *mw* and equal to or less than 500 *mw*
3—Power > 500 *mw*
4—*r-f/i-f*
5—Switching & Computer

Under Type

A—Alloyed
D—Diffused or Drift
G—Grown
M—Microalloy
O—Other
S—Surface Barrier
UNI—Unijunction Transistor

Under f αb

* Maximum Frequency
\# Figure of Merit

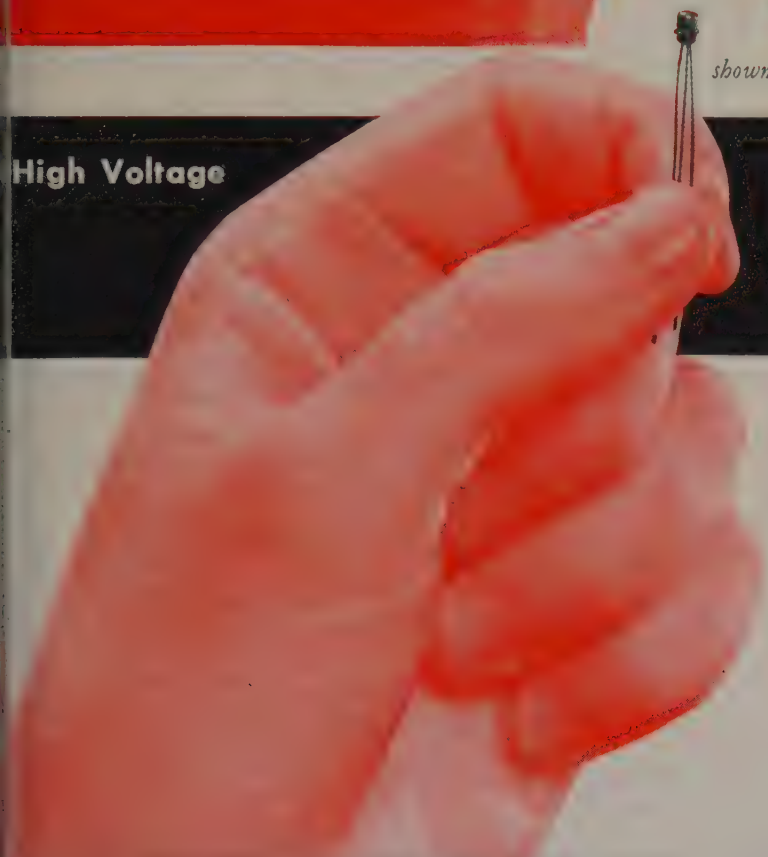
Other

6—without cap
7—2N405 with flexible leads
8—2N407 with flexible leads
9—2N409 with flexible leads
10—2N411 with flexible leads
11—2N420 with terminal cap
12—Tetrode
13—In Either Direction
14—Class B
15—Rise time 0.5 μsec max; storage plus Fall time 0.6 μsec max.

For more information circle No. 67 on Reader Service Card

First From PHILCO . . .

New Micro-Miniature Transistor Family



shown here actual size

High Voltage

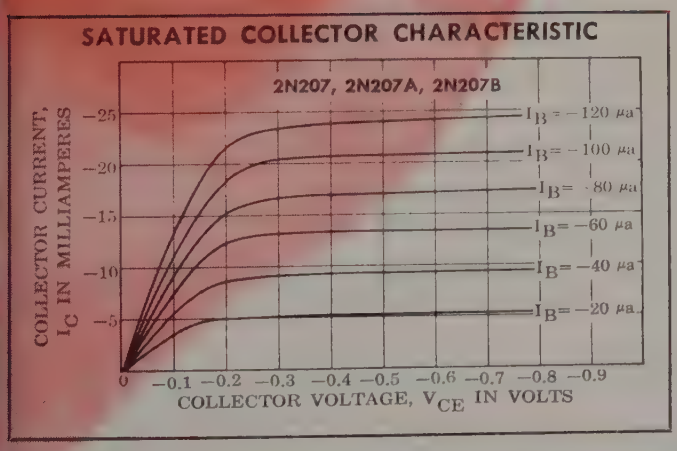
- ★ High Beta
- ★ Excellent Switch
- ★ Low Saturation Voltage
- ★ Outstanding Performance

Here is a completely new family of micro-miniature transistors, featuring proven reliability in industrial control systems, miniature hearing aid amplifiers, computers and business machines, direct-coupled amplifier and switching circuits, and audio output for miniature radios.

Among these six new transistors will be found the low-cost answer to a tremendous variety of important transistor problems. Our engineers will be happy to discuss specific applications with you.

Make Philco your prime source of information for all transistor applications.

Write to Lansdale Tube Company, Division of Philco Corporation, Lansdale, Pa., Dept. SP-158



MICRO-MINIATURE FAMILY APPLICATION DATA

MAX. DISSIPATION = 50 MW.

TYPE	MAX. RATING		TYPICAL PERFORMANCE		
	V_{CE} max.	I_C max.	$f_{\alpha b}$	h_{fe}	NOISE FIGURE
2N207	12	20 ma		100	12 db
2N207A	12	20		100	9 db
2N207B	12	20		100	4 db
2N534	50	10		100	
2N535	20	20	2.0 mc	100	12 db
2N536	20	30	2.0 mc	V_{BE} = 0.3v and V_{CE} = .06v with I_C = 10 ma I_B = 1 ma	

PHILCO CORPORATION

LANSDALE TUBE COMPANY DIVISION

LANSDALE, PENNSYLVANIA

SEMICONDUCTOR & SOLID-STATE BIBLIOGRAPHY

TITLE	PUBLICATION	CONDENSED SUMMARY	AUTHORS
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Transistor Tone Control Circuits	Audio Engineering Sept., 1957	Circuit discussion and derivation.	F. D. Walhauer
Two Channel Transistor Remote Amplifier	Audio Engineering Sept., 1957	Details of a broadcast type amplifier transistorized with two inputs.	P. K. Haahr
Low Noise Transistor Microphone Amplifier	Audio Engineering Oct., 1957	Discussion of factors in developing a microphone amplifier using transistors.	J. J. Davidson
High-Voltage Conductivity-Modulated Silicon Rectifier	The Bell System Technical Journal July, 1957	It is shown that the magnitude and temperature dependence of the currents can be explained on the basis of space-charge generated current.	H. S. Veloric M. B. Prince
Servo Modulators II Electromechanical, Electronic and Semiconductor Diode Units.	Control Engineering Oct., 1957	Discussion of copper-oxide, selenium germanium and silicon rectifier element modulators.	Basil T. Barber
Transistor Magnetic Amplifiers	Electrical Manufacturing Sept., 1957	Circuit design taking into consideration the peculiar characteristics of both transistors and magnetic amplifiers.	N. Jasper J. C. Taylor W. T. White
Transistors in Airborne Power Supplies	Electrical Manufacturing Oct., 1957	Part A—Circuit design for a transistor power supply for CRT applications. Part B—Circuit design for a transistorized *d-c* to *d-c* converter.	M. S. Chester J. W. Moody
Measuring *AC* Currents in Transistor Circuits	Electronic Design Vol. 5. No. 17 Sept. 1, 1957	Circuit description for measuring signals as low as 0.1 μA in conjunction with a *vtvm*.	J. W. Sullivan
Class B Transistor Power Amplifier Design	Electronic Design Vol. 5. No. 18 Sept. 15, 1957	Second in series (1st appeared July 15th). Effect of source and load impedances on distortion is examined. Temperature effects discussed.	R. Minton
High Frequency Diffused-Meltback Transistors	Electronic Design Vol. 5. No. 18 Sept. 15, 1957	Description and characteristics of diffused-meltback transistors and process.	A. B. Phillips A. M. Intrator
Transistor Switching Circuits	Electronic Design Vol. 5. No. 19 Oct. 1, 1957	Discussion of transistorized Schmitt Trigger and Eccles Jordan flip-flop circuits.	M. Smith
High Frequency Transistor Oscillator	Electronic Design Vol. 5. No. 19 Oct. 1, 1957	Design of nearly-harmonic, grounded-base transistor oscillators at above-critical frequencies.	J. George Adashko
Transistor *D-C* Chopper Amp.	Electronic Engineering August, 1957	Detailed description includes design procedure and performance figures.	P. L. Burton
A Stabilized *D-C* Power Supply	Electronic Engineering Sept., 1957	A-C operated device incorporates negative feedback to provide low output resistance for stable variable output voltage of 0 to 30 *V* at currents up to 1 *amp*.	T. H. Brown W. L. Stephenson
A Low Voltage Stabilizer Employing Junction Transistors and a Silicon Junction Reference Diode	Electronic Engineering Sept., 1957	Series voltage stabilizer uses Zener diode as reference voltage source. Change of output impedance with frequency is also investigated.	D. Aspinall
Circuit Techniques Associated With Transistor Broadcast Receivers (Part I)	Electronic Engineering Sept., 1957	Special circuit problems and technical solutions discussed. Various receiver designs presented.	J. N. Barry
Circuit Techniques Associated With Transistor Broadcast Receivers (Part II)	Electronic Engineering Oct., 1957	Applications to oscillator and mixer, *r-f* and antenna input, and *agc* circuit among topics discussed.	J. N. Barry
A Simple Physiological Stimulator Using a Transistor Oscillator Circuit	Electronic Engineering Oct., 1957	Instrument replaces conventional induction coil in experiments in which a simple stimulator is required.	W. T. Catton L. Molyneux B. Schofield
Transistors in High-Frequency Amplifiers	Electronic & Radio Engineer July, 1957	Properties and behavior of transistors at high frequencies.	W. Guggenbuhl M. J. O. Strutt
Transistor RC Oscillators	Electronic & Radio Engineer August, 1957	Effect of transistor capacitance is discussed in various network configurations.	M. K. Achuthan
Rural Carrier System Uses Transistors	Electronics August, 1957	Transistorized transmitter and receiver uses double-sideband transmission to effect selective calling of up to 10 telephone subscribers per wire pair.	B. R. Stachiewicz

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ransistor Lab Relay	Electronics August, 1957	Two matched 2N109 transistors employed in balanced input and one 2N44 in relay coil circuit.	Harry A. Gill
easuring Parameters of Junc-n Transistors	Electronics August, 1957	Article describes method of measuring hybrid parameters of a junction transistor.	R. W. Hendrick, Jr.
nijunction Transistor Forms ip-Flop	Electronics Sept., 1957	Unijunction transistor in multi-vibrator circuit effects economy of components.	E. Keonjian J. J. Suran
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ulse Generator Uses Junction ransistors	Electronics Sept., 1957	Circuit achieves pulse amplitudes 28 *V* neg. and 50 *V* pos. Other characteristics discussed.	Edw. J. Fuller
est Equipment for Transistor oduction	Electronics Oct., 1957	Parameter measurements with go-no go indicator and conventional meter. Measures power gain and distortion.	Andrew B. Jacobs Carl G. Tinsley
ransistors Boost Video for TV udio Monitors	Electronics Oct., 1957	Description of compact transistor preamplifier for use with standard TV receiver as studio line monitor.	L. N. Merson
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lectrical Conductivity of used Quartz	Journal of Applied Physics July, 1957	Two specimens are studied. One behaves as an electronic conductor. The other exhibits dielectric anomalies and polarization effects.	Julius Cohen
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xygen Content of Silicon ingle Crystals	Journal of Applied Physics Aug., 1957	Explanations of oxygen content effects are advanced, and the influence of various pulling parameters is discussed.	W. Kaiser P. H. Kech
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Effect of Irradiation on the Hole Lifetime of *N*-Type Ger-manium	Journal of Applied Physics Oct., 1957	Results of irradiating large single crystal samples of *n*-type germanium with fast neutrons and gamma rays are discussed.	O. L. Curtis J. W. Cleland J. H. Crawford, Jr. J. C. Pegg
Optical Measurement of Film Growth on Silicon and Ger-manium Surfaces in Room Air	Journal of Electro-Chemical Society Oct., 1957	Thickness and growth kinetics of oxide films on polished silicon and germanium exposed to room air were obtained and measured.	R. J. Archer
A Quantitative Theory of Elec-tro Formation of Metallic Ger-manium Point Contacts	Journal of Electronics Aug., 1957	Forming conditions are discussed. Quantitative computations are provided.	A. Sin
Effect of Compression and An-nealing on the Structure and Electrical Properties of Ger-manium	Journal of the Institute of Metals July, 1957	Domain structure having small angle boundaries is produced by high temperature deformation.	E. Greiner P. Breidt J. Hobstetter W. Ellis
Some Aspects of Alloying Onto Germanium Surfaces	Journal of the Institute of Metals July, 1957	Conditions for satisfactory alloying are presented.	J. W. Patterson J. McGlasson W. C. Hittinger

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Observation of the Drift of Germanium Circuits by Field Experiment	Journal of Physics (Japan) April, 1957	An etched surface of N-Type germanium shows drift in room air. Experimental procedure used to measure the effect.	M. Kikuchi
A Transistor Marker Beacon Receiver	IRE Transactions A.N.E. Sept., 1957	Junction transistors and diodes are used to replace tubes and relays in newly designed one-light marker beacon receivers.	R. G. Erdmann
A Transistorized Phase-Shift Power Oscillator	IRE Transactions on Audio June, 1957	Comparisons are made between transistor and tube circuits.	L. J. Giacoletto
Audio Emitter Bypassing in Transistor Circuits	IRE Transactions on Audio June, 1957	An equivalent circuit analysis of the common emitter amplifier yields a simple relation for circuit parameters.	R. P. Murray
Transistor Feedback Amplifiers	IRE Transactions on Broadcast & TV Receivers June, 1957	Discussion of factors which bear upon the design of transistor feedback amplifiers. Confined to *h-f* behavior.	R. Page Burr
Determination of Transistor Performance Characteristics at Very High Frequencies	IRE Transactions on Broadcast & TV Receivers June, 1957	Design considerations of matching networks and their particular application to transistor measurement.	G. E. Theriault H. M. Wasson
Counting Circuits Employing Ferroelectric Devices	IRE Transactions on Circuit Theory Sept., 1957	Discussion of ferroelectric devices and theory application in counting circuits.	R. M. Wolfe
A High-Speed Two-Winding Transistor-Magnetic-Oscillator	IRE Transactions on Circuit Theory Sept., 1957	Discussion of various transistor-magnetic-core circuits, their analysis and design.	A. J. Meyerhoff R. M. Tillman
Millimicrosecond Transistor Current Switching Circuits	IRE Transactions on Circuit Theory Sept., 1957	Description of a new mode of operation whereby well-specified currents can be switched reliably with small voltage swings.	Hannon S. Yourk
Some New Transistor Bistable Elements for Heavy Duty Operation	IRE Transactions on Circuit Theory Sept., 1957	Part 1—Description and analysis of a nonsaturated circuit. Part 2—Controlled saturation in transistors, and its application on switching circuits.	N. F. Moody C. D. Florida
A Decade Ring Counter Using Avalanche-Operated Junction Transistors	IRE Transactions on Circuit Theory Sept., 1957	Advantages of avalanche-operated junction transistors in a decade ring counter and driver are discussed. Circuits are given.	J. E. Lindsay
Transient Response Characteristics of Unijunction Transistors	IRE Transactions on Circuit Theory Sept., 1957	Discussion of device theory, equivalent circuit, small-signal results, transient analysis, and switching circuits.	S. J. Suran B. K. Eriksen
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Some Solutions to Problems of Operating Germanium Transistor Servo Amplifiers at High Ambient Temperatures	IRE Transactions on Circuit Theory Sept., 1957	Discussion of design techniques for transistor equipment which must operate at high ambient temperatures.	P. M. Thompson J. Mitchell
Bias Considerations in Transistor Circuit Design	IRE Transactions on Circuit Theory Sept., 1957	Consideration of stabilizing operating point of a transistor. This paper develops a solution to this problem.	Sorab K. Ghandi
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ansistorized Logging Probe	Nucleonics October, 1957	Description of a probe with a 1 inch O.D. suitable for use with small diameter oil well tubing.	F. E. Armstrong
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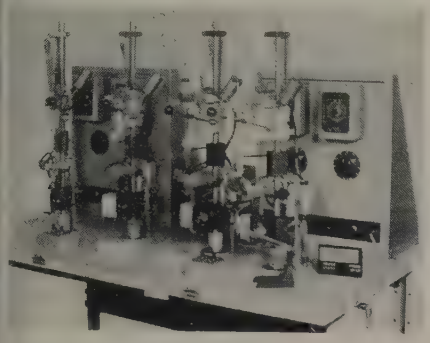
IRE Standards on Letter Symbols for Semiconductor Devices, 1956	Proceedings of the IRE July, 1957	A uniform system of letter symbols for electrical quantities and parameters applied to semiconductor devices.	S. J. Angello, Chairman, et al
Carrier Generation and Recombination in *P-N* Junctions and *P-N* Junction Characteristics	Proceedings of the IRE Sept., 1957	Current due to generation and recombination of carriers from generation-recombination centers in a space-charge region of a *p-n* junction.	C. T. Sah R. N. Noyce W. Shockley
Design Theory of Deflection Layer Transistors	Proceedings of the IRE Oct., 1957	Discussion and design theory of a new class of *h-f* transistors, the "deflection layer" type.	W. W. Gartner
Crystal Diodes as Mixers	Proceedings of the IRE Sept., 1957	Effects of barrier resistance, barrier capacity and spreading resistance of a crystal diode on conversion loss at uhf and microwave frequencies are discussed.	G. C. Messenger C. T. McCoy
Current-Capacitance Characteristics of Metal Rectifiers	Proceedings, Physical Society Oct., 1957	Findings of measurements made of Cu_2O and Selenium rectifiers at room and at liquid air temperatures.	Y. Moriguchi A. Okazki
On the Thermal Capture of Electrons in Semiconductors	Proceedings, Royal Society Sept., 1957	The influence of the acoustic vibrations on the lattice on the capture of free carriers by impurities is investigated thoroughly.	G. Richayzen
The Equivalent Circuit of the Drift Transistor	RCA Review Sept., 1957	The 4-terminal admittances for the drift transistor have been examined as functions of frequency and approximated by an equivalent circuit.	J. Almond R. J. McIntyre
A Transistorized Horizontal-Deflection System	RCA Review Sept., 1957	A completely transistorized developmental-horizontal deflection system is described consisting of an oscillator, driver, output stage and phase detector.	H. C. Goodrich
Transistor Receiver Video Amplifier	RCA Review Sept., 1957	General design problems are discussed and a practical amplifier is described.	M. C. Kidd
Quasi-Electric and Quasi-Magnetic Fields in a Non-Uniform Semiconductor	RCA Review Sept., 1957	Discussion of effect of a non-homogeneous impurity distribution on the forbidden bandwidth.	H. Kroemer
Dielectric Spectroscopy of Ferromagnetic Semiconductors	Review of Modern Physics July, 1957	Topics included and discussed in this article are dielectric spectroscopy, measurement techniques and principles of dielectric analysis.	P. A. Miles W. P. Westphal A. Von Hippel
Generation of an *EMF* in Semiconductor Non-Equilibrium Current Carrier Concentrations	Review of Modern Physics July, 1957	Topics included and discussed in this article are current density equations, and various types of photo-voltaic effects.	J. Tauc
Design For An Improved High Frequency Transistor	Tele-Tech & Electronic Industries July, 1957	Silicon surface alloy transistors designed to meet military high temperature, high frequency applications. Data concerning frequency range and parameters.	G. Thornton J. Roschen T. Miles
Unique Properties of the 4-Layer Diode	Tele-Tech & Electronic Industries Aug., 1957	Description and discussion of a new bistable two-terminal semiconductor device.	W. Shockley
Germanium Rectifiers as Electronic Components	Tele-Tech & Electronic Industries Aug., 1957	Discussion of germanium rectifiers; advantages, characteristics, applications.	J. T. Cataldo
Effects of Radiation on Semiconductors	Tele-Tech & Electronic Industries Aug., 1957	Describes an elaborate radiation test facility and results.	J. W. Clark
Transistor Data for Logical Circuit Design	Tele-Tech & Electronic Industries Oct., 1957	The problem is to determine which characteristics completely describe the performance and what variations in these characteristics are important.	R. B. Hurley
Measuring Transistor Power Gain at High Frequencies	Tele-Tech & Electronic Industries Oct., 1957	Description of a unique circuit which measures common emitter power gain directly in the 40-300 *mc* range.	W. N. Coffey
Progress Report on Semiconductors	Tele-Tech & Electronic Industries Oct., 1957	Discussion of silicon, germanium, and selenium rectifiers, their preferences in high temperature and high current applications.	Norman S. Bech

New Products . . .

Glass Diode Sealing Machine

A new semi-automatic glass diode sealing machine, No. 2948, has been announced by Kahle Engineering Company, North Bergen, N. J., that produces 700 glass diodes per hour for semiconductor manufacturers. A fully automatic model, can produce

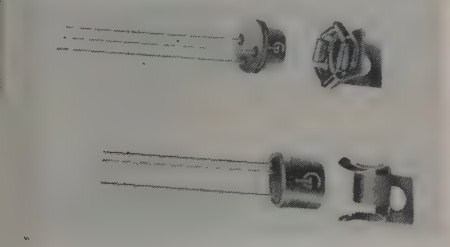


up to 2000 units per hour. In the semi-automatic model, the machine has four individual positions. The operator loads each in turn and when the fourth is loaded, the first is ready to be unloaded. After loading, all operations are automatic and controlled. The entire cycle takes less than 25 seconds.

For further information
check No. 1 on Reader Service Card

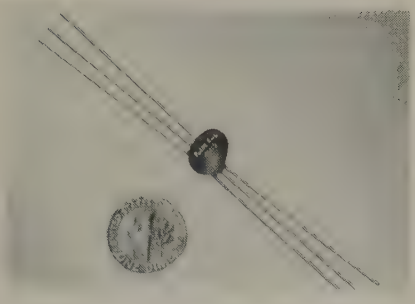
Heat Sinks

Beryllium copper heat sinks are available from General Transistor Corp., Jamaica, N. Y. in two models. The General Transistor heat sink enables the transistor to operate at higher levels of dissipation and provides a mounting clamp for the



transistor in those cases where the transistor is suspended by its leads and not used with a socket. Model HS-10 is designed for the GT soldered case and Model HS-20 for the GT version of the JETEC 30 case.

For further information
check No. 2 on Reader Service Card



Pulse Transformer

A tiny pulse transformer, no bigger than a pea, is now available from Pulse Engineering, Inc. Designated the ES3, this subminiature transformer is particularly useful in transistor blocking oscillator circuits. Body dimensions for the epoxy resin encapsulated pulse transformer are ⅜" maximum. The ES3 is available in two and three winding styles with wire leads of No. 24 AWG tinned copper. Coil inductances to 3 millihenries are available. Power rating of these units is 1 watt average power and 50 watts peak pulse power.

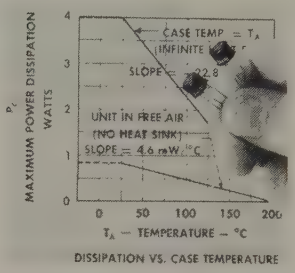
For further information
check No. 3 on Reader Service Card

Decade Capacitor

The Type 980-G and Type 980-H Decade Capacitance Units are new assemblies of the new Type 505 Capacitors to furnish decades of 0.01 μf and 0.001 μf per step, respectively, manufactured by General Radio Co. Previously available was the Type 980-F with 0.1-μf steps. A new Type 980-P1 Switch is used in these decades and is also available separately. The switch is a low-capacitance, low-loss unit which complements the characteristics of the Type 505 Capacitors to provide low-loss decades suitable for use in a-c bridges,

resonant circuits and filters. An assembly of the three decades in a "decade box" is available as the Type 1419-K Decade Capacitor. This unit, with a maximum capacitance of 1.11 μf in steps of 0.001 μf, replaces the older Type 219-K Dissipation factor of the new decades is one-third that of the older units and the long-term stability of capacitance values is better than 0.1%.

For further information
check No. 5 on Reader Service Card



DISSIPATION VS. CASE TEMPERATURE

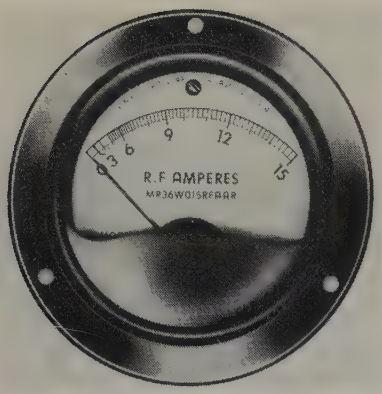
Diffused Base Silicon Transistors

Texas Instruments announces two new diffused-base silicon medium power transistors. Original equipment manufacturers can now design and build transistorized medium power circuits utilizing the two new transistors' 4-watt at 25°C case temperature and 1-watt at 150°C case temperature dissipation ratings. These high dissipation/high temperature ratings are a built-in safety factor for designers of lower power circuitry. Both new *n-p-n* transistors feature a typical saturation resistance of only 20 ohms at 25°C plus an operating range of −65°C to +200°C. To insure the guaranteed specifications of these new devices, they are temperature stabilized at 215°C. These diffused-base transistors are well adapted to high temperature switching applications because of the high peak currents resulting from the 1-watt/150°C dissipation and 20-ohm saturation ratings.

For further information
check No. 44 on Reader Service Card

Thermocouple R-F Ammeters

A new line of thermocouple type RF Ammeters is announced by the Meter Division, Sun Electric Corporation, Chicago 31, Illinois. Described as having thermocouple characteristics of unusual sensitivity,

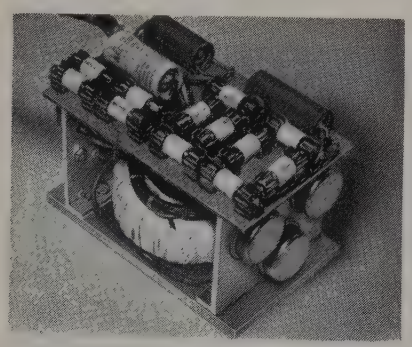


the double wire construction makes possible the withstanding of greater overload, less power consumption, plus inherent cool-running, trouble-free operation. Meters are of Ruggedized design, conforming to Specification MIL-M-10304 and are available for panel mounting in 1½, 2½, 3½ and 4½ inch diameters in ranges up to 0-15 amperes RF.

For further information
check No. 7 on Reader Service Card

Transistorized D-C to D-C Converters

A complete range of transistorized static d-c to d-c converters for use where reliability and size are important is now available from the UAC Electronics Division of Universal Transistor Products Corp. These compact, lightweight units are specifically designed to convert battery voltage DC to high voltage DC in two-way radios, public address



amplifiers, or wherever conventional power supplies are used. They are fully rectified and filtered, and have a transistor reliability of 95% in 10,000 hours of use. A typical transceiver supply (pictured) produces three outputs: 500 V *d-c* @ 165 *ma*, 270 V *d-c* @ 150 *ma*, and —55 V *d-c* @ 10 *ma*—from a 12 V *d-c* input; comes in a 3½" x 5" x 3" package.

For further information
check No. 8 on Reader Service Card

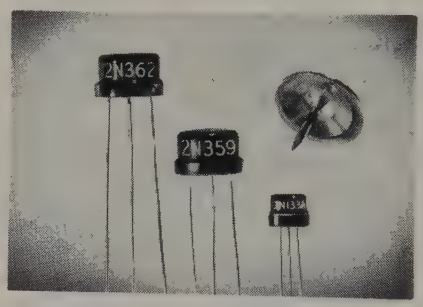
Power Resistors

Type P-1 is a new addition to the line of Precision Power resistors manufactured by MEPCO. It meets the requirement of MIL-R-26C, Style RW 59, Characteristic G. 1% is the standard tolerance but it is also available in tolerances down to .1% on special order. Rated at 2.5 Watts at 70° C derate to zero at 275° C. Temperature Coefficient .002%/° C. Length ½". Diameter ¼".

For further information
check No. 9 on Reader Service Card

Transistors

Twelve new germanium p-n-p transistors for audio applications have been added to Raytheon's line. Six in the JETEC-30 package are for driver and output use as follows: Types 2N362 and 2N363 are drivers

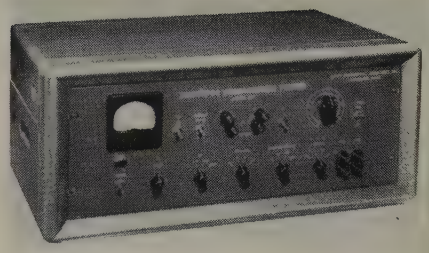


with average beta ratings of 90 and 45 respectively. 2N422 is a low noise unit with maximum noise factor of 6 db. Types 2N359, 2N360 and 2N361 are all capable of 500 milliwatts output in class B but differ in beta and power gain ratings. The other six new types are in an ultra-small package having a total volume of approximately 0.004 cubic inches. Types 2N130A, 2N131A and 2N132A are amplifiers wiht beta ratings of 22, 45 and 90 respectively. 2N133A is a low noise amplifier with maximum noise factor of 6 db 2N138B is an output type capable of 50 milliwatts in Class B. Type CK754 is a high gain transistor with an average beta of 300.

For further information
check No. 10 on Reader Service Card

Power Transistor Characteristic Plotter

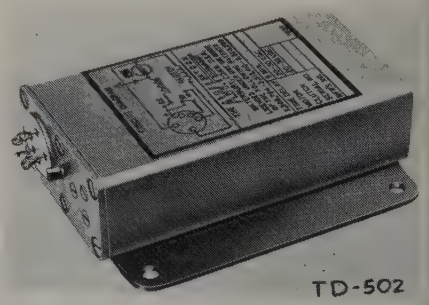
The Dunn Engineering Model 341 Power Transistor Characteristic Plotter is a compact power transistor curve tracer which makes possible the observation of any of the three families of junction transistor characteristic curves on the face of an auxiliary oscilloscope. The Model 341 Plotter generates a pair of curves, displayed continuously and simultaneously, for each of the three basic families. These curves, available for both the common-base and common-emitter connection, are obtained by applying to the input terminals of the transistor an adjustable bias on which is superimposed a current square wave.



For further information
check No. 11 on Reader Service Card

Time Delay Relays

The A. W. Haydon Company has just announced the release of a new bulletin AWH TD-502 describing a new line of sub-miniature hermetically sealed time delay relays. These units were designed for aircraft, missile and rocket applications and will also be used by industry where space and weight are at a premium. Requiring only one-quarter of the space of standard time delay relays, these tiny units weigh only ½ as



much. The 4300 series will be used for direct current units and the 25300 series will be used for 400 cycle units. Time Delay settings from 1 second to 1 hour can be supplied on *d-c* units and time delay settings from 15 seconds to 3 hours can be supplied on 400 cycle units. Up to 3 switches can be supplied in the basic design of these sub-miniature units.

For further information
check No. 14 on Reader Service Card

SAF Type Silicon Rectifiers

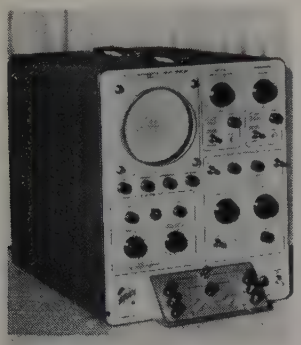
Designed and manufactured to the xtremely rigid requirements of IL-E-1/1089 (USAF), three USAF pes of silicon rectifiers (IN538, N540, and IN547) are now in large ale production and available for nmediate quantity delivery by the utomatic Manufacturing Division f General Instrument Corporation.

he new rectifiers, which cover the ange of 200 to 600 volts peak in- erse, are rated at *d-c* output cur- ents of 750 *ma* at 25° C. ambients nd 250 *ma* at 150° C. ambients. hese rectifiers are of alloyed junc- ion construction, with all-welded ermetic seal. Developed for use in ll types of military equipment, where the basic limitations of selen- um, germanium and vacuum tube ectifiers must be overcome, these nits are designed for high reliabil- ty under the most severe conditions f moisture, vibration, high acceler- tion vibration, centrifuging, shock nd temperature cycling. They can e operated successfully at temper- atures ranging from —55°C. to +165°C. and they can be stored at emperatures ranging from —65°C. o +180°C.

For further information
check No. 16 on Reader Service Card

Transistor Curve Tracer

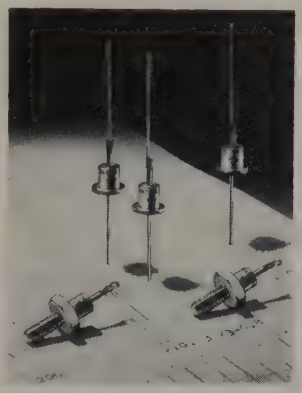
This new precision instrument manufactured by Tektronix, Inc., traces characteristic curves for both *p-n-p* and *n-p-n* transistors on the face of a cathode-ray tube. It has a 10-ampere collector supply and a 2.4-ampere base supply. Displays 4 to 12 curves per family, with input current from 1 microamp-per-step to 200 milliamps-per-step, or input voltage from 0.01 to 0.2 volts-per-step. Vertical deflection is calibrated in collector current, base voltage, base current, and base source voltage. Horizontal deflection is calibrated in collector voltage, base voltage, base current, and base source voltage. Seven different transistor characteristics are accurately plotted for examination and measurement. 16 dissipation-limiting resistances and 24 driving resistances are available. Single-family or repetive display can be selected. Transistor characteristics can be displayed in either the common-emitter or common-base configuration.



For further information
check No. 23 on Reader Service Card

Zener Diodes

Exceptionally low temperature coefficient and zener impedance over the voltage range are features of the zener types now available from International Rectifier Corporation. Of interest to the design engineer is the fact that full calibration data is supplied with each diode, showing a plot of the zener voltage and zener impedance. A complete series in



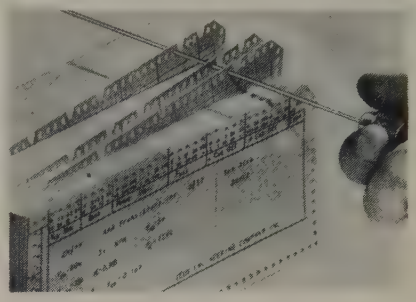
each of the two types is now in full production. The Style "S" series, of pigtail type construction, is rated at 1.0 watt over a voltage range from 3.9 volts to 30 volts, in 10% voltage steps. The Style "T" zener diode series is stud mounted, and is rated at 3.5 watts over a voltage range from 3.9 to 30 volts in 10% voltage steps (when mounted on a 2" x 2" x .025 copper fin.)

For further information
check No. 30 on Reader Service Card

Transistor Index

A unique "Transistor Index" has been introduced by Zeus Engineering Corporation to facilitate selection of the optimum transistor for a given application. This method utilizes punched cards which contain pertinent transistor data. Transistor selection is rapidly obtained by manual needle sorting on the basis of desired parameters. Thus, no machinery of any kind is required. This method eliminates the frustration of searching through volumes of data sheets. It also provides a compact central transistor file. The "Transistor Index" provides rapid access to a large quantity of information and yet is extremely simple to use.

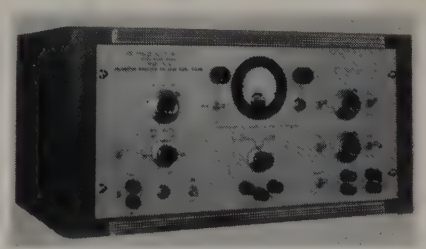
For further information
check No. 46 on Reader Service Card



Unijunction Transistor Analyzer

Polyphase TA-10 Unijunction Transistor and Diode Checker traces on an oscilloscope the negative resistance or emitter characteristic curves of the G.E. type ZJ14 unijunction transistor (double based diode type). Interbase and emitter voltages are metered and adjustable by front panel controls. Semiconductor Diode Checking of all types of diodes is readily performed by oscilloscope display of forward and reverse current characteristic curves. Go, no-go type quality control and production checking procedures are easily set up. A transistor circuit power supply is automatically provided because of the instrument's power supplies rated at 100 volts, 100 milliamperes.

For further information
check No. 21 on Reader Service Card



Miniature Molded Transformers

Microtran Company, Inc. has introduced a new line of Micro-Miniature size molded transformers designed for transistor, audio and servo applications. These transformers are molded of high temperature epoxy to provide protection against extremes in ambient. Weighing ½ oz. the dimensions of this "MM-M"

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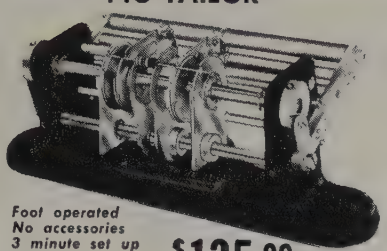

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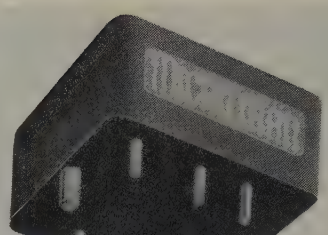
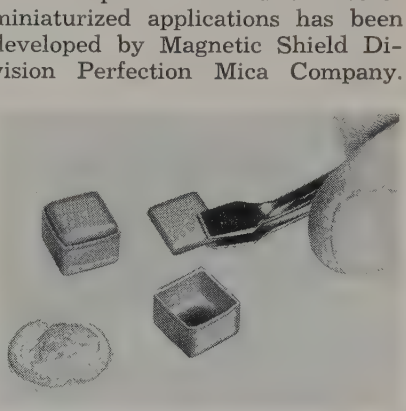


series is ¾" x ⅞" x ½" high. Mounting is by means of standard channel ears, threaded studs, or inserts. Terminal pins are arranged for use with dip soldered printed circuitry. Catalog is available listing electrical ratings in which this new "MM-M" type may be obtained.

For further information
check No. 17 on Reader Service Card

Shielding Capsules

A new line of subminiature Co-Netic magnetic shielding capsules designed for subminiature reactors and transformers used in transistorized and printed circuits and other miniaturized applications has been developed by Magnetic Shield Division Perfection Mica Company.



When required, shields can be pretinned for soldering without affecting magnetic shielding qualities. Shielding capsules may be produced in a wide variety of shapes and dimensions using standard methods or special hydroform techniques.

For further information
check No. 25 on Reader Service Card

Junction Transistors—RCA

The 2N411 and its flexible-lead version, the 2N412, are germanium-alloy junction transistors of the p-n-p type. They have characteristics which are controlled especially to meet the requirements of converter and mixer-oscillator applications in the Standard AM Broadcast Band. In a common-emitter type of fixed circuit, these transistors feature a conversion power gain of 32 db at 1 megacycle per second. Moreover, the parameters of the transistors are controlled to provide satisfactory operation under low-voltage conditions. These transistors are hermetically sealed, utilize a metal case, and are small in size. The 2N411 has a maximum diameter of 0.260" and a maximum seated length of 0.495"; while the 2N412 has a maximum diameter of 0.240" and a maximum length including flexible leads of 0.405".

For further information
check No. 22 on Reader Service Card

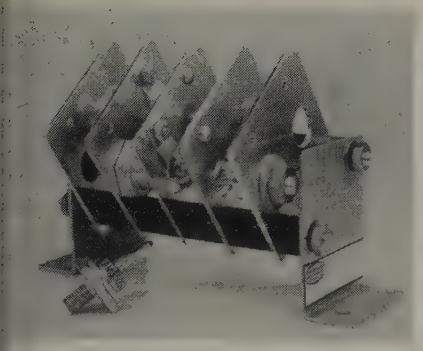
VHF-UHF Transistors

Philco Corporation announces a major breakthrough in high frequency transistor technology and production—an entirely new class of "field accelerated" transistors capable of operating through the entire very high frequency (*vhf*) and part of the ultra high frequency (*uhf*) spectrum. These new Philco transistors are called MADT, Micro Alloy Diffused-base Transistors. They have been made possible by the MADT process and according to Philco represent a tremendous advance in the electronic capabilities of transistors. It is asserted they will have a great impact on the design and application of advanced electronic equipment formerly beyond transistorization. They operate at switching speeds comparable to the speed of light, speeding up the logic computational performance of computers required for missile tracking and interception. Philco claims that high performance military communication equipment will be possible, also, radar *i-f* amplifiers, wideband video amplifiers and other critical high performance circuitry can now be transistorized.

For further information
check No. 43 on Reader Service Card

Silicon Rectifier Stacks

Designed to meet high power rectification applications for which a limited amount of space is available, stack assemblies of silicon rectifiers are now available for delivery by the Automatic Manufacturing Division of General Instrument Corporation. Pictured above is a single phase full wave bridge assembly, rated at 25 amperes average rectified current at an RMS input of 245 volts with forced air cooling, utiliz-



ng 2" x 2" fins. The over-all dimensions of this assembly are 5" x 3" x ". Developed for use in all types of military and commercial equipment where the basic limitations of other types of rectifiers must be overcome, these units are designed for high reliability under the most severe environmental conditions of moisture and vibration fatigue, high acceleration vibration, centrifuging, shock and temperature cycling. They have been successfully operated at ambient temperatures ranging from −50°C. to +165°C., and they can be stored at temperatures ranging from −65°C. to +180°C.

For further information
check No. 28 on Reader Service Card

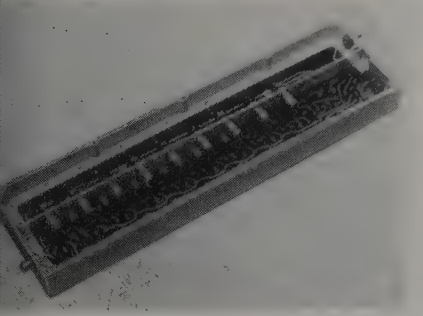
Transistor Clips

Atlas E-E Corp., makes available a cross reference data sheet listing their clips for each of the transistors available on the market.

For further information
check No. 12 on Reader Service Card

Transistorized I-F Strip—LEL, Inc.

The series 80B transistorized i-f strip was designed for prototype



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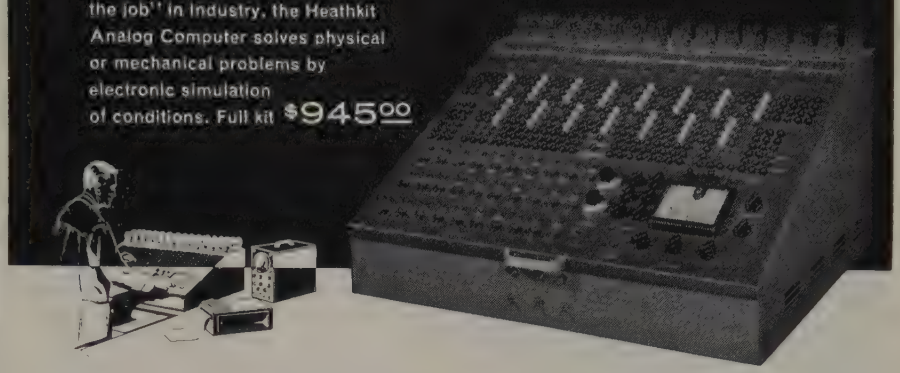

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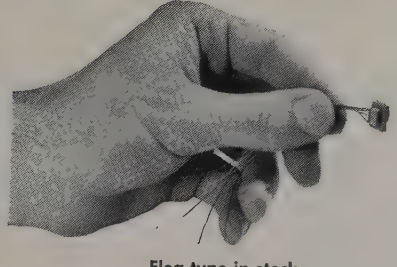

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system work and as an aid to conversion of existing radar or missile circuitry to transistor form. Originally available only at a center frequency of 30 mc, it now can be supplied at both 30 and 60 mc center frequencies. The specifications noted are nominal design center values. Values given for bandwidth and center frequency change with temperature are tentative and not checked on individual units.

For further information
check No. 31 on Reader Service Card

Semiconductor Diode and Rectifier List Derivation & Tabulation Assoc.

A new comprehensive compilation by this electronic component data service is now available. The September Edition includes 1,451 different types which are listed in order of electrical characteristics (*i.e.*, PIV, minimum $I^{\prime}$) for easy reference, with separate technical sections on general purpose diodes, rectifiers, Zener reference diodes, computer diodes, microwave mixer diodes, microwave video detector diodes, and miscellaneous types. In addition, there is a cross-index in order of type number indicating all manufacturers of each type, and a section enumerating the manufacturers, along with all types each produces. A one-year subscription includes complete editions in September and March.

For further information
check No. 34 on Reader Service Card

Chemical Compounds

The City Chemical Corporation announces the production and distribution of a series of pure chemical compounds used in the growing of crystals for semi-conductor research. The following compounds are available for prompt shipment: Potassium Cobalticyanide, Barium Cobalticyanide, Potassium Chromicyanide, Potassium Manganicyanide, Sodium Manganicyanide, Barium Ethyl Sulfate, Potassium Ethyl Sulfate, Potassium Methyl Sulfate, Gadolinium Ethyl Sulfate, Lanthanum Ethyl Sulfate, Sodium Propyl Sulfate, Cadmium Silicofluoride, Cobalt Silicofluoride, Zinc Silicofluoride, Nickel Silicofluoride, Aluminum Acetylacetonate, Chromium Acetylacetonate, Copper Acetyl acetonate. Facilities are available for the production of any related compounds which may be requested by laboratories doing microwave research. Inquiries for special purity compounds are also invited.

For further information
check No. 49 on Reader Service Card

1958 Transistor Data Chart

Kahle Engineering Company, North Bergen, N. J., designers and builders of special automatic and semi-automatic equipment for all industrial applications, have just completed a four-page 1958 transistor data chart. The brochure features complete, up-to-date technical specifications and application data for almost 500 transistors now available, and includes over 170 new types introduced during recent months.

For further information
check No. 15 on Reader Service Card

Unijunction Transistor

The General Electric Company announces that it has characterized and registered six types of silicon unijunction transistors with JETEC. The unijunction transistor is the nearest solid-state equivalent of a small controlled-grid thyratron. The six numbers assigned by JETEC to this new component are 2N489 through 2N494. All six types are now in full production at the Company's plant.

For further information
check No. 20 on Reader Service Card

High Voltage Power Transistor

A *p-n-p* germanium alloy high voltage power transistor designed for use in computer, telephone, and aircraft circuits has been added to the renewal line of Sylvania Electric Products Inc. The 2N296 features welded hermetic seal construction and has a collector current of two amps.

For further information
check No. 39 on Reader Service Card

Subminiature Silicon Diode

A uniquely versatile subminiature silicon junction diode, 1N658, has been brought out by General Instrument Corp.'s Semiconductor Division through its Radio Receptor Co. subsidiary. The new diode, designed for computer, communications, military and general circuit requirements, as well as moderate power applications, features high conductance, fast recovery, high peak inverse voltage, low reverse leakage and a broad operating temperature range. Forward voltage drop is under 1 volt at 100 *ma*, with a .3 μ*sec* reverse recovery. Peak inverse voltage is 120 volts, with a reverse leakage of .05μ*a* at —50 volts and 25 degrees C., and 25 μ*a* at —50 volts at 150 degrees C.

Operating temperature range of the new silicon diode is from —65 degrees C to 175 degrees C. It will

handle an average rectified current of 200 *ma* and has a power dissipation rating of 200 *mw*.

For further information
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Constant Current Converter—North Hills Elec. Co.

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Oregon Electronic Mfg. Co. makes available regulated voltage and current supply Model CV-10-10 in a single unit for transistor engineering. Provides adjustable current and voltage limiting.

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Transistor List—D.A.T.A.

Third Edition (October 1957) and Supplement of January 1958 of this quarterly publication are now available. The October List includes 645 different types, a 40% increase since the Second Edition in April 1957. The transistors are listed in order of electrical characteristics for easy reference (*i.e.*, maximum collector dissipation, $f\alpha_b$ with separate technical sections on junction, power, and point-contact transistors. In addition, there is a cross-index in order of type number indicating all manufacturers of each type, and a section enumerating the manufacturers, along with all types each produces.

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Book Reviews . . .

Title: Selection and Application of Metallic Rectifiers
Author: S. P. Jackson
Publisher: McGraw Hill Book Company, New York, N.Y.

This book is intended to provide reference information to enable the circuit designer to minimize cut and try techniques in the application of metallic rectifiers in favor of a more analytical approach.

Section one deals with rectifier circuits (Chap. 2) and complex loads and filters (Chap. 3). It was felt that design information on the Pi-type capacitive-resistive filter should have been included here since this type of filter is rarely treated well, however in all other respects the derivations and design charts are adequate and clear.

Section two of the book deals with the selection of the proper types of rectifier. A chapter written by a separate author is devoted to each popular variety of rectifier. These chapters contain a wealth of design and descriptive information on each type to aid in the selection of the proper unit for a specific application.

The third section (Chapts. 11 to 16) presents various applications to specific categories of usage such as battery charging, electroplating, and industrial supplies.

In its entirety the book is exceptionally well written and should more than ably fulfill its objective.

Title: An Introduction To Junction Transistor Theory
Author: R. D. Middlebrook
Publisher: John Wiley & Sons Inc., New York, N.Y.

This book is carefully divided into three parts, each part presenting a general aspect of the material to be covered.

Part one deals with the structure of the germanium and silicon crystals based upon the energy band theory. The introductory chapter deals with the initial *p-n* junction rectifier and the point contact transistor. The following chapters present a clear qualitative development of the physics and mathematical interpretation of current flow in semiconductors.

Part two relates the derivations of part one to the solutions for the cur-

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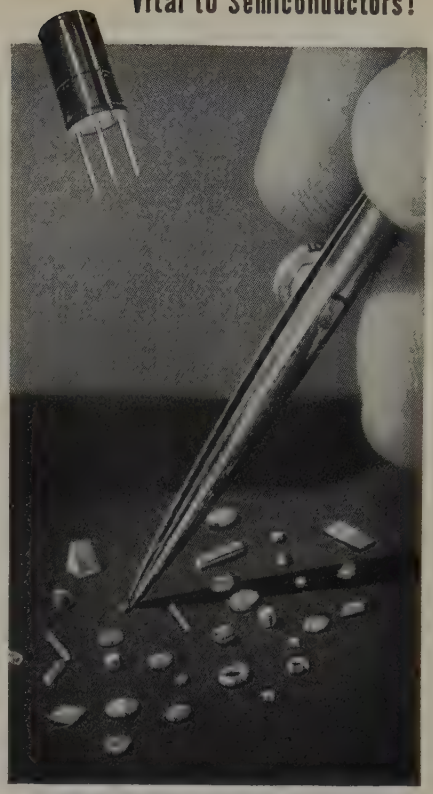

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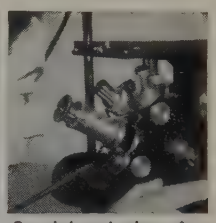

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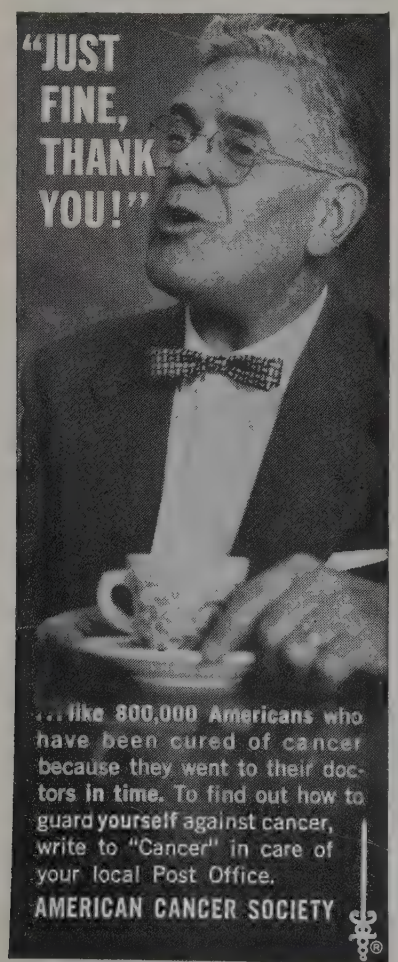
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rent as a function of the applied voltages for the p-n-p transistor and p-n junction. Chap. 8 deals with the p-n-p transistor as a natural outgrowth of the p-n junction. The equations and diagrams illustrating the mobile carrier density and current density distributions are especially interesting. A generalized solution for the continuity equation of minority carriers is presented and a complete small-signal AC equivalent circuit is analyzed.

The third part of the book explores a modified a-c equivalent circuit (Chap. 13) of considerable value to the circuit designer. A method of computation of the equivalent circuit element values is developed and the results compared to the measured quantities. Much of this work, done by the author, is of an original nature and is excellent.

The book itself is written in a tutorial manner and is well illustrated. The author has done a commendable job in relating much obtuse theory to a practical understanding of transistors.

Title: An Introduction To Semiconductors
Author: W. Crawford Dunlap Jr.
Publisher: John Wiley & Sons Inc., New York, N.Y.

This book, a very thorough presentation of the physical aspects, of semiconductors, will undoubtedly find useage as a text book on the subject. The material is presented in a highly understandable form with a notable sufficiency of mathematics.

The author introduces semiconductors on the basis of their distinctive properties as crystalline materials and illustrates their lattice structures. The customary wave mechanical approach follows, and appropriately precedes a well written chapter on "Statistical Mechanics." The electron theory is presented as a means of description of the various measurable properties of semiconductors. From this point the author deals with contact and surface properties and properties of the p-n junction.

The use of semiconductors as rectifiers, transistors and photocells are adequately treated in separate chapters, again in a physical or mode of operation sense.

An Introduction To Semiconductors is a well written, thorough coverage of the subject which presents its material in a practical manner well suited to the design engineer or engineering student.

Stephen E. Lipsky

INDUSTRY NEWS

Transistor Sales

Factory sales of transistors in September increased over the number sold in August and nearly treble the number of such semiconductor devices sold in September of last year, the Electronic Industries Association reported. Cumulative sales of transistors in the first nine months of this year increased substantially over the same period last year. Factory sales of transistors in September totaled 3,231,000 units with a dollar value of $6,993,000 compared with 2,709,000 transistors sold in August with a dollar value of $6,598,000 and 1,115,000 units worth $3,455,000 sold in September of last year, EIA reported. Cumulative sales of these semiconductor devices during the first nine months of this year totaled 18,842,300 units valued at $49,056,000 compared with 8,113,000 transistors sold during the like months of 1956 with a dollar value of $23,172,000.

IRE National Convention

March 24 through 27 have been selected as the dates for the 1958 IRE National Convention, to be held again at the Waldorf-Astoria Hotel and New York Coliseum in New York City. More than 55,000 engineers and scientists from 40 countries are expected to attend what has become the world's largest and most important technical convention. The 1957 convention drew 53,811. A comprehensive program of 275 papers, covering the most recent developments in the fields of all 27 IRE Professional Groups, will be presented in 55 sessions at the Waldorf-Astoria and the Coliseum. The high point of the program will be two special symposia on "Electronics in Space" and "Electronic Systems in Industry," to be held Tuesday evening, March 25. The complete program will be announced in January. The Radio Engineering Show which will occupy all four floors of the Coliseum, has been expanded to accommodate approximately 850 exhibitors. Some $12,000,000 worth of the latest electronic equipment will be on display, much of it for the first time.

ens Plant in England

Texas Instruments Limited, a olly-owned subsidiary of Texas truments Incorporated, of Dallas, xas, formally opened its new plant Oct. 1, 1957 for the manufacture transistors and other semiconduc- devices and their marketing roughout the sterling area coun- es. The plant is the first Texas struments manufacturing facility be established outside the United ates. The group of subsidiaries own as Geophysical Service Inc. aintains offices at strategic points roughout the world in support of ore than seventy crews engaged der contract to oil companies in ophysical exploration for petro- um in some seventeen countries in th hemispheres.

ansistorized Dosimeter

The Federal Civil Defense Admin- ration, Battle Creek, Michigan, as approved and ordered into pro- uction, 23,199 *transistorized* dosi- eter chargers for Civil Defense se. The unit is manufactured by niversal Transistor Products Corp., Sylvester Street, Westbury, New ork.

eneral Transistor Expands

General Transistor Corp. will start roduction of germanium and silicon mputer diodes and silicon rectifi- s early next year, and also expects be turning out diffused base tran- stors in the near future, according Herman Fialkov, president. Gen- ral Transistor, has acquired a new lant at 87-11 130th Street, Rich- mond Hills, Queens, in its program f "planned growth," Mr. Fialkov nnounced. The plant, General Tran- istor's fourth on Long Island, has 6,000 square feet for the company's ew diode division. "This new build- ng is to be ready for occupancy round November 15, and we expect o be in production early next year," Mr. Fialkov said. "We are planning o install the latest automatic and emi-automatic equipment in the ew plant."

Radio Receptor Completes Consolidation

Radio Receptor Co., Inc., has com- leted consolidating semi-conductor roduction under one roof at its big, main plant at 240 Wythe Ave. Brooklyn, one of three buildings it has in the area, according to Isidor B. Seidler, general manager. The consolidation began a year ago when the company, a General Instrument Corp. subsidiary, assigned the top floor of the block-long, four-story Wythe Ave. building to selenium rectifiers to be manufactured according to a process developed by the Siemens organization of West Germany.

IRE Elects Officers for 1958

Donald G. Fink, Director of Research of the Philco Corporation, has been accorded one of the highest engineering honors with the announcement of his election as president of the Institute of Radio Engineers for 1958. Mr. Fink succeeds John T. Henderson, Principal Research Officer of the National Research Council, Ottawa, Canada, as head of this international society of 62,000 radio engineers and scientists. Carl-Eric Granqvist, Director of Svenska Aktiebolaget Gasaccumulator, Stockholm-Lindingo, Sweden will succeed Yasujiro Niwa, President of Tokyo Electrical Engineering College, Tokyo, Japan as IRE Vice President.

New Plant

The opening of U. S. Semiconductor Products, Inc., new Phoenix plant is of great importance to manufacturers using silicon Zener diodes in voltage regulation circuits, especially where abnormal temperatures are encountered or where it is necessary to have matched pairs or quads. According to *Friedrich W. Schwartz*, president of the company, U. S. Semcor's new plant is entirely dust-free, temperature-controlled, an atmospheric-conditioned for absolute cleanliness of the finished product.

Price Reductions Announced

Price reductions in silicon diodes used in missiles and computers was announced recently by Pacific Semiconductors, Inc., Culver City, California. "Gains in efficiency associated with expanding volume have made possible price reductions of as much as fifty percent," said Warren B. Hayes, company manager of operations. Mr. Hayes gave as examples a heretofore "hard-to-manufacture" silicon diffusion computer diode used for high speed switching (3/10 of a millionth of a second) which has been reduced from $8.00 list to $4.80 and an advanced type of subminiature silicon rectifier which has been reduced from $8.00 to $4.00 list. About fifty items of silicon and germanium diodes and silicon rectifiers have been reduced with the greater price drop being reflected in the more complex types, he said.

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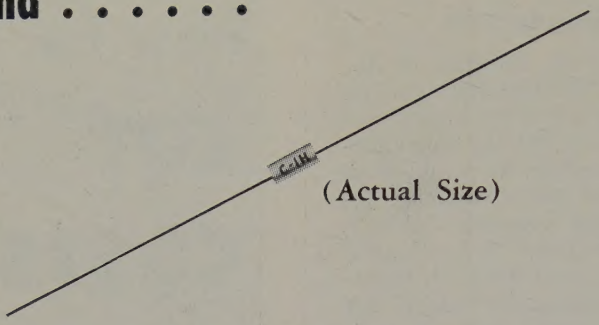

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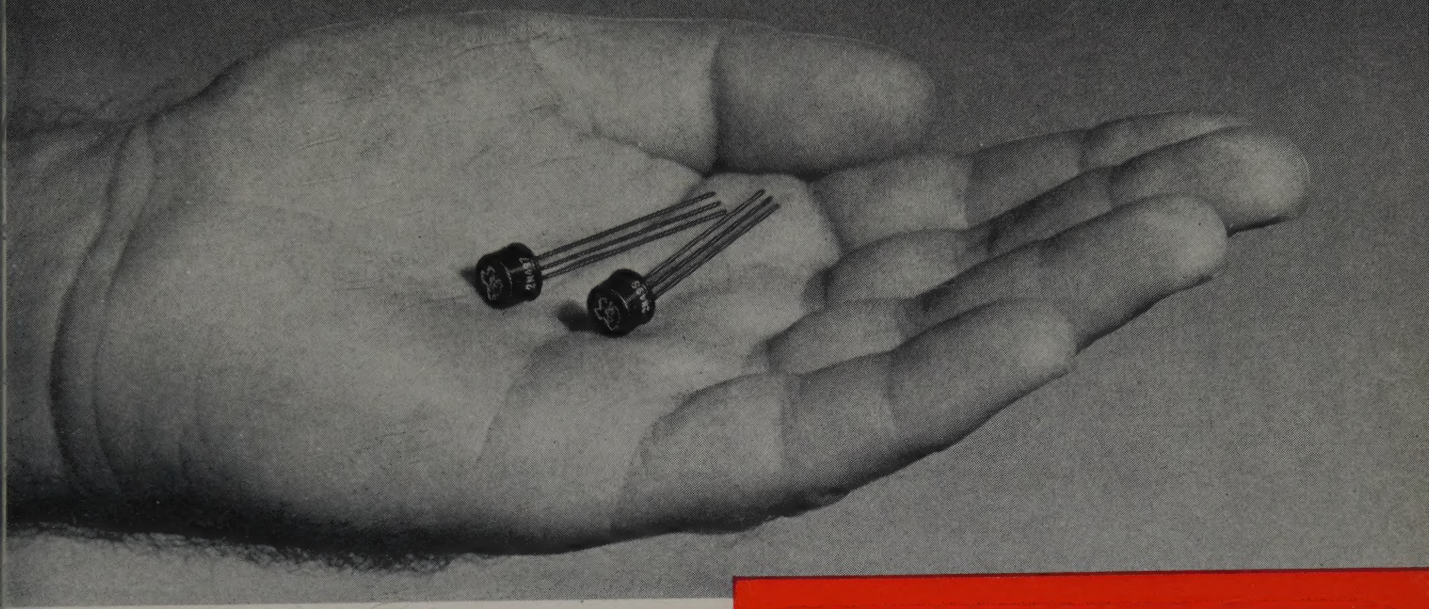

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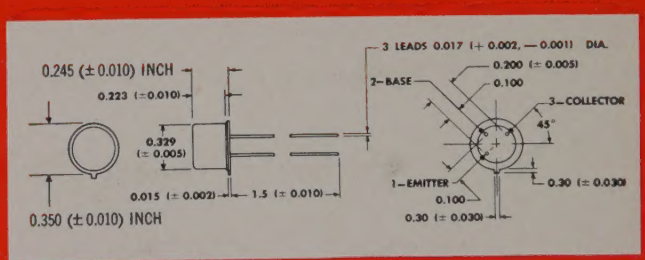

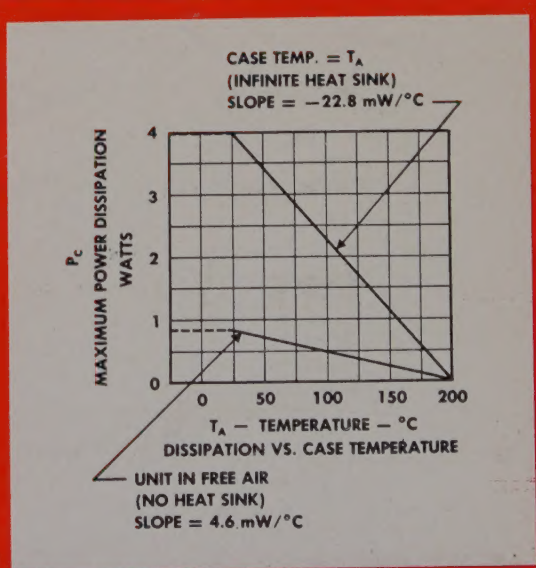

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BV_{EBO}	(I_E = 250 μA)	8	8	V
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		min.	des. cen.	max.	unit
R_{CS}	(I_B = 40 mA; I_C = 200 mA)	—	20	40	Ohm
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